AN EMPIRICAL EVALUATION OF
THREE KNOWLEDGE ACQUISITION TECHNIQUES
FOR DEVELOPING A PROJECT MANAGEMENT
RELATED EXPERT SYSTEM

THESIS

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THESIS

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Captain Todd T. Vikan

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Abstract

The acquisition of expert knowledge is recognized as one of the major hurdles facing the expert system programmer or knowledge engineer. Unfortunately, knowledge acquisition is seldom addressed in any detail in expert system literature, even though there exist a number of different techniques that a knowledge engineer can use to capture expert knowledge. The purpose of this study was to identify and evaluate the relative effectiveness of three knowledge acquisition techniques that may be used when developing expert systems for project management related tasks. The three techniques were interview, concept mapping, and interruption analysis. An experiment was conducted and quantitative measures of effectiveness were derived. These measures included technique implementation times, times to formulate expert system production rules, the total number of rules and the inferences required to complete those rules, the number of translations of the expert knowledge to encode an expert system rule, and the contribution each technique made to a final expert system that represented an aggregate of all the expert knowledge collected. While no one technique was clearly superior, used together, concept mapping and interruption analysis were found to be powerful tools for acquiring expert knowledge.

AN EMPIRICAL EVALUATION OF THREE KNOWLEDGE ACQUISITION TECHNIQUES FOR DEVELOPING A PROJECT MANAGEMENT RELATED EXPERT SYSTEM

I. Introduction

General Issue

Advances in computer software technology, coupled with the growth of microcomputer hardware, have made computer-aided decision support and expert systems available to virtually all Air Force managers. However, one of the fundamental difficulties encountered when developing an expert system is not the software or hardware, but acquiring the expert knowledge that must be incorporated into the system. This knowledge must be extracted from human experts in sufficient quantity and quality so that it can be translated and programmed into a computer. While many knowledge acquisition techniques exist, little if any empirical evidence exists to indicate which knowledge acquisition techniques may be preferred for specific subject areas (often referred to as "knowledge domains").

Specific Purpose

The purpose of this study is to identify and evaluate the relative effectiveness of three knowledge acquisition techniques that may be used when developing expert systems for project management related tasks.

Research Objectives

With the many knowledge acquisition techniques available, one technique or combination of techniques should prove effective in aiding the development of a work breakdown structure microcomputer expert system.

The following are the research objectives of this thesis:

1. Understand the nature of the work breakdown structure development process.

2. Identify current knowledge acquisition techniques being used in the field of expert system technology.

3. Select three knowledge acquisition techniques to use in extracting knowledge to develop an expert system to aid the creation of a project work breakdown structure.

4. Field test these three knowledge acquisition techniques.

5. Analyze the results of the field test of the three knowledge acquisition techniques.

6. Develop a simple expert system based on the techniques.

7. Validate the expert system to see how well it reflects the knowledge of the experts who participated in this evaluation.

Assumptions and Standards

Knowledge acquisition is recognized as the "bottleneck" in the burgeoning field of expert system technology (3:144). Even though many acquisition techniques have been identified, the difficulty lies in selecting a technique that meets four essential criteria:

1. It is a technique appropriate for the knowledge being collected;

2. It is relatively easy for the system programmer (or knowledge engineer) to use;

3. It produces a body of knowledge in a form that does not require complex interpretation (knowledge that is unambiguous); and

4. It produces the knowledge in a form that can be encoded in the appropriate decision rules required for the computer.

Scope and Limitations of This Research

The scope of this research is limited to the fundamental considerations affecting knowledge acquisition. Knowledge acquisition, as used in this study, is the collection and translation of an expert's knowledge into a format suitable for a particular expert system. The difficulty associated with this task lies in the difference between the representational format required for the expert system and the basic form of the knowledge itself (10:168).

This research examines the extraction of knowledge for one particular problem area or domain: project management. Due to time constraints, not all knowledge acquisition techniques or problem tasks could be investigated. As such, one representative task, that of project work breakdown structure development, was the goal of the expert system, and three knowledge acquisition techniques were evaluated.

II. Methodology

Overview

As stated in Chapter I, the acquisition of expert knowledge is one of the primary difficulties facing the expert system programmer or knowledge engineer. This difficulty is compounded by the fact that few guidelines exist to help the expert system programmer with the acquisition of expert knowledge (5:155). The goal of this research is to help an expert system programmer, whether a novice or an accomplished knowledge engineer, identify and implement an appropriate knowledge acquisition technique for the task at hand.

As a basis for this research, a detailed literature review was conducted examining expert system technology and the expert system application problem domain selected for this research. Chapter III provides an introduction to the knowledge acquisition techniques evaluated by this research and a summary of relevant information on the problem domain: project management. A separate report, titled "An Introduction to Expert Systems and Knowledge Acquisition Techniques" was written as a result of this literature review. "An Introduction to Expert Systems and Knowledge Acquisition Techniques" provides a general description of expert systems, expert knowledge, and knowledge acquisition. This report was published separately (9).

The literature reviews examined text books, professional journals, other theses, Air Force regulations, and military standards.

The following paragraphs explain the methods used to address the seven research objectives outlined in Chapter I.

Objective 1: Understand the nature of the work breakdown structure development process. A literature review provided the basis for an understanding of the use and development of a work breakdown structure. Chapter III provides a summary of this information. The background literature consisted of textbooks on project management, Air Force regulations, Air Force pamphlets, and Military Standard-881, which deals specifically with the work breakdown structure.

The literature review was supplemented by discussions with those knowledgeable in the work breakdown structure process. These individuals are assigned to the Air Force Institute of Technology and Aeronautical Systems Division (ASD) at Wright-Patterson AFB, OH. These individuals provided insight into how the Air Force, and more specifically, how ASD implements the work breakdown structure for its many projects and programs.

Objective 2: Identify current knowledge acquisition techniques being used in the field of expert system technology. A detailed literature review was conducted to

determine what knowledge acquisition techniques are currently being used in the field of expert system technology. This literature review resulted in the publication of the companion report titled "An Introduction to Expert Systems and Knowledge Acquisition Techniques" (9). This companion report provides an overview of expert system technology, expert knowledge, a brief definition of each recognized knowledge acquisition technique, the types of knowledge that these techniques were reported to be appropriate for, and recognized limitations of each technique.

Objective 3: Select three knowledge acquisition techniques to use in extracting knowledge to develop an expert system to aid in the creation of a project work breakdown structure. From the selection of recognized knowledge acquisition techniques found in the literature, three techniques were selected for evaluation. The three techniques were interview, concept mapping, and interruption analysis (task observation). Each of these techniques is described in Chapter III. In general, these techniques were selected based on the opinions of the literature authors as to the merits of each technique for the selected application, and the type of knowledge that each technique was suitable to acquire.

Information presented in the literature indicated that each of these knowledge acquisition techniques was

potentially suitable for acquiring knowledge about a task where a verbal description of the expert's problem solving process was possible. Based on discussions with individuals knowledgeable about work breakdown structures, the task of developing a work breakdown structure was assumed to be explainable.

<u>Objective 4: Field test these three knowledge acquisition techniques</u>. A quasiexperiment was conducted to assess the relative effectiveness of the three selected techniques. Each knowledge acquisition technique was evaluated using a different expert.

The process of identifying experts involved discussions with individuals from Aeronautical Systems Division's Cost Management Systems Division of the Directorate of Cost (ASD/ACCM). LtCol Thomas Bowman recommended using experts from a program office cost analysis directorate. The Directorate of Program Control (ASD/RWP) from the Electronic Combat and Reconnaissance Systems Program Office was contacted. The office expressed an interest in this research project and, more importantly, a willingness to participate.

Individual experts were identified through personal interviews and recommendations from peers within the cost analysis directorate. Besides their knowledge, the two dominant characteristics desired of the experts were a willingness to participate in this research and assured

availability. Experts volunteered to participate in this experiment.

Three approximately one-hour sessions were used to extract each expert's knowledge. A fourth meeting was used to review the information collected during the course of the previous sessions to identify any errors or omissions. Each session was audio-taped in addition to any written notes taken. Each session was conducted at a location that was convenient and comfortable to each expert.

Before the actual knowledge acquisition began, the investigator practiced each knowledge acquisition technique. The practices were conducted using experts in the same general field as those participating in the experiment. One-hour practice sessions involving the interview and the interruption analysis techniques were conducted. The interruption analysis practice was conducted during an actual program initiation meeting involving the expert who participated in the interview evaluation. However, the interruption analysis practice took place after the three interview sessions were completed. A two-hour practice concept mapping session was conducted.

Objective 5: Analyze the results of the field test of the three knowledge acquisition techniques. Six quantitative measures were identified as a means to assess the relative effectiveness of the three knowledge acquisition techniques. These measures were as follows:

1. The total time required to implement each technique. This included actual interaction time with the expert, preparation time, and the time required to transcribe and integrate information from the audio-tapes and notes into a single written transcript.

2. The number of rules and facts produced.

3. The time required to formulate rules from the written transcripts.

4. The number of inferences required to complete rules.

5. Each technique's contribution, measured in the number of rules, to the final expert system.

6. The number of intermediate steps required to translate the expert's knowledge into an expert system rule.

Objective 6: Develop a simple expert system based on information collected from each of the three techniques. As stated in Item 6 in the previous objective, a simple expert system was created using the knowledge from each of the three experts.

Objective 7: Validate the expert system to see how well it reflected the knowledge of the experts who participated in this project. To validate the expert system, the system was demonstrated to the participating experts. Each expert was asked to solve a simple test case using the expert system. The expert system's decision rules and output were evaluated to determine if the problem

solving methodology and solutions to the case were the same as those expected by the experts. Discrepancies and errors were traced to determine if they resulted from errors in programming, unfounded assumptions on the part of the system developer that were the consequence of incomplete information, or actual errors in the experts' thought processes when they communicated the information to the system developer.

Summary

The purpose of this research effort was to evaluate knowledge acquisition techniques within the context of expert system development. Knowledge extracted by three recognized knowledge acquisition techniques was evaluated to determine if the form and content of the data could be readily used to develop the expert system knowledge base rules and facts. An expert system, created as a part of this research, was evaluated by the participating experts to ensure that the system produced acceptable output and to determine the source of any errors that may have occurred.

III. Literature Review

Topic Statement

This chapter reviews the literature on knowledge acquisition processes that were potentially useful in developing an expert system knowledge base to aid the development of a project work breakdown structure. An expert system is a computer system that emulates or copies the human cognitive decision and problem solving process (12:395). As stated previously, historically, the acquisition of expert knowledge has caused difficulty during the development of expert systems. While this obstacle is acknowledged as one of the primary difficulties encountered in expert system development, there is no universally accepted reason why (3:144).

Method of Treatment and Organization

This literature review contains literature that supports an empirical evaluation of the knowledge acquisition techniques available to the expert system developer or knowledge engineer. The primary goal of this literature review is to acquaint the reader with the knowledge acquisition techniques used in this research and a specific task that this technology may be applied to. It provides an overview of knowledge acquisition, and specific definitions and methodologies for the three knowledge acquisition techniques evaluated by this research. It also

provides an overview of a specific problem domain, and identifies and describes a particular task within that domain that is suitable for expert system application.

Resources

The literature used for this research effort consisted of professional journals, technical publications, Air Force regulations and military standards, theses, and textbooks about expert systems, artificial intelligence, and project management. Although the authors writing about artificial intelligence and expert systems discussed many facets associated with these fields, a common thread throughout much of the literature was the difficulty surrounding the acquisition of expert knowledge (3:144; 15:152).

Knowledge Acquisition

"The elicitation of knowledge from experts is a time-consuming process and is usually conducted in the absence of a systematic conceptual design. Few guidelines are available to help the knowledge engineer map out his/her course and pursue it efficiently" (5:155). There are many difficulties associated with developing an adequate knowledge base for an expert system. These difficulties can be attributed to the diversity of knowledge forms, and the difficulty of managing the knowledge data base (1:103). The primary difficulty facing the knowledge engineer is

accessing the "...abstract generalizations of the expert's knowledge domain" (1:123).

Within the context of expert system technology, knowledge acquisition is the collection and translation of expert problem solving ability from a knowledge source to a computer program (2:129). Olson identifies two general classes of acquisition techniques--direct methods and indirect methods. Direct methods focus on the knowledge that can be directly articulated, explicit knowledge. Direct methods include, among others, interviews, questionnaires, protocol analysis, interruption analysis, task observation, drawing closed curves and inferential flow analysis (15:153-166).

Belkin states that these "direct methods" can be grouped into the main acquisition techniques of the interview, verbal protocol analysis, and observational studies. Interviews may be either structured or informal. Verbal protocol analysis is analyzing the problem solving process as experts verbalize their thought processes while solving a task. Observational studies are data collection efforts for actual problems in the expert's natural working environment. According to Belkin, current practice is to use a combination of techniques, and certain techniques may be more suitable for specific types of knowledge (2:129-130).

According to Olson, indirect methods collect information that requires inferences to be made about the exact nature of the expert's knowledge. Indirect methods attempt to extract implicit expert knowledge. Indirect methods include multi-dimensional scaling, Johnson's hierarchical scaling, general weighted networks, ordered trees from recall, and repertory grid analysis (15:153-166).

These lists of direct and indirect knowledge acquisition techniques do not represent all of the various techniques currently being used. They are merely an attempt to convey to the reader the great variety of forms available to the knowledge engineer. Other methods not found to easily fit within the previous two categories include concept mapping or visual modelling, discourse analysis, and storyboarding. The most common knowledge acquisition method, however, is the interview (15:153). Olson recommends beginning any knowledge acquisition effort with an unstructured interview (15:154).

Olson goes on to caution that no matter which technique or techniques are used, each acquisition technique (direct or indirect) may lead to incorrect rules and relations. "The knowledge engineer must make judgments of the suitability of a method for knowledge elicitation for the kinds of knowledge the expert is assumed to possess" (15:167).

While there exist many different knowledge acquisition techniques described throughout the literature, this research focused on the interview, concept mapping, and interruption analysis. This was done because these three knowledge acquisition techniques appeared to meet the "Assumptions and Standards" as set forth in Chapter I of this report. Those three techniques are discussed below, and all techniques assessed during the research are discussed in the companion volume to this report (9).

Interviewing. According to Olson, the interview is the most common knowledge acquisition technique (15:153). In essence, "the exchange of information is the central purpose of the interview" (8:54). The interview involves conversational interaction between individuals to convey information about a particular subject. The interview is considered a direct method of knowledge acquisition. In other words, the interview is best suited to knowledge that can be articulated (15:153).

In general terms, interviews can be classified as either standardized (structured) or non-standardized (unstructured). A standardized interview seeks to gather the same information from a number of different respondents. To insure this uniformity, the same questions are asked of each respondent. The structured interview can be further divided into scheduled interviews, where the questions are

asked in the same order, or non-scheduled interviews, where the order and wording of the questions may be varied (8:60).

Non-standardized interviews do not pose all the same questions to all of the respondents. As such, answers cannot be statistically manipulated to analyze group responses or to compare individual responses to the aggregate. Unstructured interviews can be classified as preparatory unstructured interviews which are done to prepare for a structured interview, or independent unstructured interviews which are not preparatory for additional interviews and have their own purpose (8:61).

Concept Mapping. Within the scope of expert system development, concept mapping can be used as a complement to an interview. Concept maps are a visual representation of hierarchical relationships among concepts. "Concept maps are intended to represent meaningful relationships between concepts in the form of propositions" (14:15). Concept mapping is potentially useful in extracting implicit expert knowledge since it focuses on concepts and relationships among those concepts.

As stated above, concept mapping is used in conjunction with interviewing techniques to produce a graphical facsimile of an expert's knowledge. As such, considerations given to proper interviewing should be applied when employing the concept mapping technique. Unlike an interview, however, the end-product of a concept mapping

session will not be a detailed transcript but a hierarchical concept map of the expert's knowledge (14:119-133). Each mapping session is guided by and builds upon the previous session's concept map. Figure 1 is a simple example of a concept map.

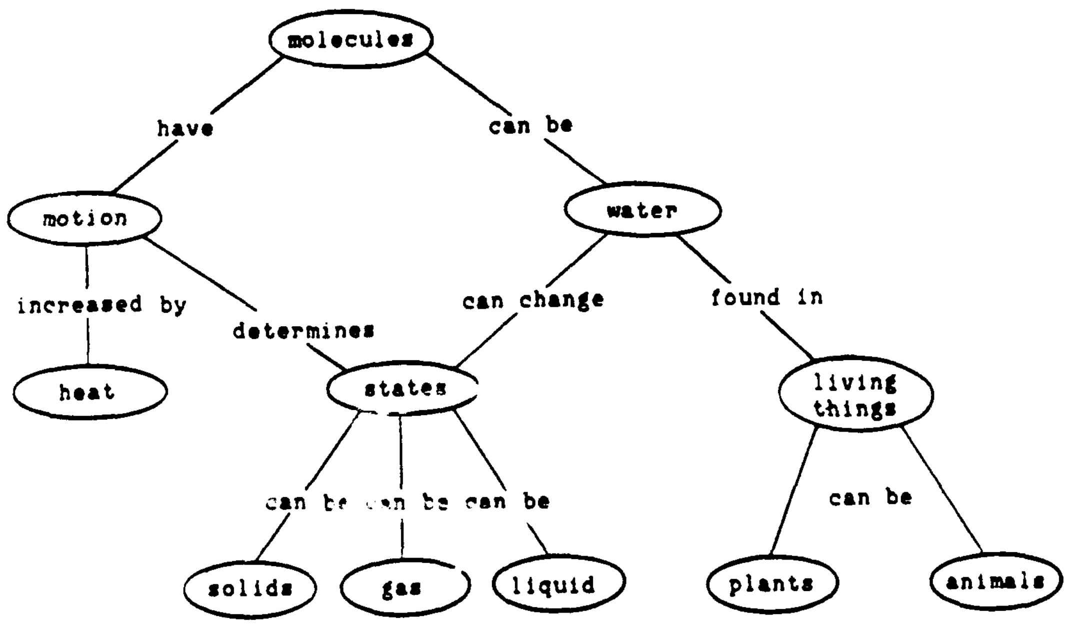


Figure 1. Example of a Simple Concept Map. (Reprinted from 14:18)

Interruption Analysis. As described in Olson's article, interruption analysis is a method for accessing explicit forms of expert knowledge. It is similar to simple task observation. The knowledge engineer observes an expert solving a specific task. Unlike task observation, however, interruption analysis allows the knowledge engineer to interrupt the problem solving process when the expert does

something the knowledge engineer cannot understand. At this point, the reasoning process and actions of the expert are examined and the expert tries to explain in detail the reasons for his actions (15:156).

Olson feels the main advantage of interruption analysis is that the knowledge engineer is able to capture an expert's knowledge at the critical moment of execution and theoretically, at the moment of greatest focus. This advantage is somewhat compromised in that the thought processes are interrupted, and they may prove impossible to restart. Olson feels this technique provides the best results when it is employed after a prototype expert system has been developed, and the knowledge engineer wishes to compare the expert system's performance to that of an expert (15:156).

Problem Domain Overview

A suitable application for expert system technology is one where there is an "existing body of expertise, and this expertise is routinely used for decision making..." (16:106). Using this liberal interpretation, almost any task would appear to be suitable. However, if the opinions of others familiar with this technology, such as Waterman, Kiem and Jacobs, and Prerau, are taken into consideration, some explicit criteria exist by which to determine if a problem domain is suitable for expert system application. A more detailed description of the criteria that can be used

to identify suitable applications for expert system technology can be found in "An Introduction to Expert Systems and Knowledge Acquisition Techniques" (9). One problem domain that appears to meet most of the existing criteria is project management.

Project management is a multifaceted discipline. As such, one working under these circumstances "is faced with many non-routine and unstructured decisions" (4:1). If a project is defined as a specific task with a specific objective, start and end dates, limited funding and resource consumption, project management involves the planning and monitoring of that project (11:2). Kerzner defines project planning as defining work requirements, defining the quantity of work, and determining the necessary resources (11:2). Project monitoring is overseeing progress, comparing actual progress to predicted progress, assessing the impact of this comparison, and adjusting to subsequent changes (11:2-3). According to Kerzner, "the major responsibility of the project manager is planning" (11:18).

"Planning in a project environment may be described as establishing a predetermined course of action within a forecasted environment" (11:575). Establishing this predetermined course of action involves many individual, yet interrelated tasks such as determining the life cycle phases of the project, general project planning, generating a statement of work (SOW), scheduling, and developing the work

breakdown structure. The development of the work breakdown structure is but one potential application for expert system technology, and is the focus of this research.

The Work Breakdown Structure. The work breakdown structure "is a product-oriented family tree composed of hardware, services, and data which result from project engineering efforts during the development and production of a defense materiel item, and which completely defines the project/program" (7:II-34). A sample work breakdown structure tree diagram is presented in Figure 2. A project manager should define all project work in elements that are manageable, independent, integratable, and measurable (11:599). The work breakdown structure provides a framework by which a project manager can accomplish this breakdown. The work breakdown structure may follow a format similar to that provided in Figure 3.

Air Force Regulation 800-17 states the policy for implementing a work breakdown structure for Air Force acquisition programs. This regulation applies to all organizations "which wish to issue requests for proposals for defense materiel items..." (6:1). According to this regulation, the work breakdown structure provides a somewhat standardized format against which all acquisition programs can be broken down into the products and services that make up a particular defense materiel item. The objective of this regulation is to ensure that the top three levels

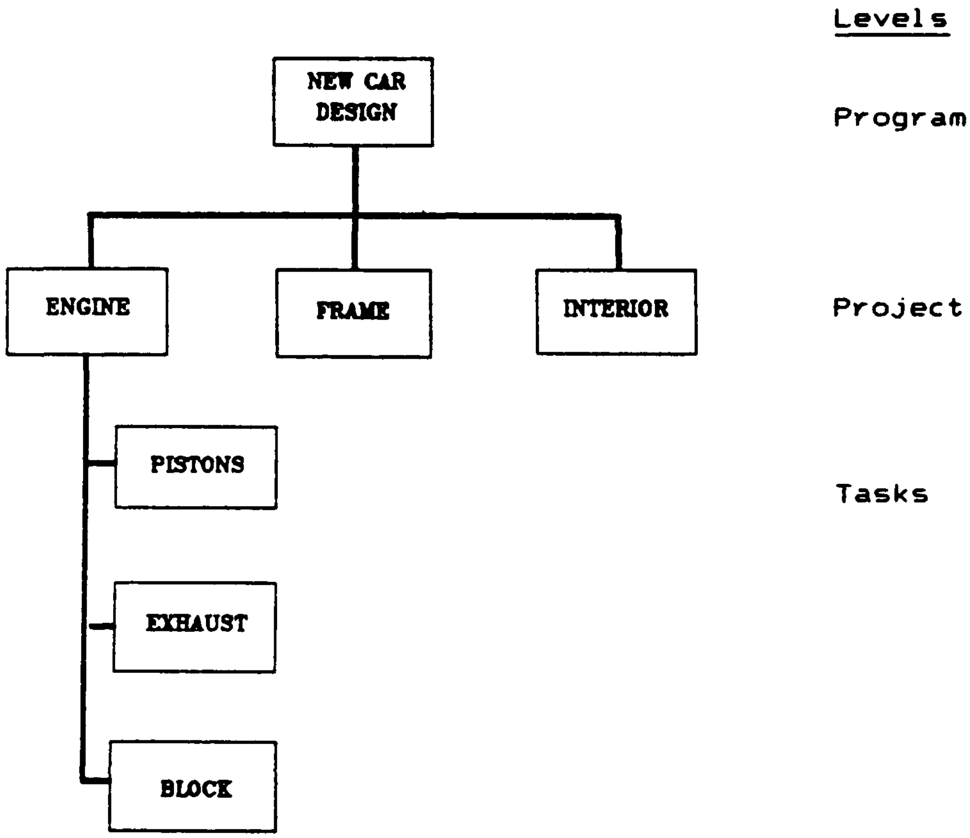


Figure 2. Example of a Work Breakdown Structure Tree Diagram (Adapted from 11:607)

Level	Description
1	Total Program
2	Project
3	Task
4	Subtask
5	Work package
6	Level of effort

Figure 3.
Generic Work Breakdown Structure
(Reprinted from 11:600)

of a work breakdown structure conform to a framework that allows accurate comparisons of similar acquisition programs.

Military Standard 881 (MIL-STD-881) is the document that directs the development of a work breakdown structure for all defense materiel items. MIL-STD-881 provides an introductory narrative explaining the purpose and various types of work breakdown structures. It also has seven appendices that provide generic work breakdown structures and element definitions for the top three levels of the major categories of defense materiel items. These categories are:

1. Aircraft Systems
2. Electronic Systems
3. Missile Systems
4. Ordnance Systems
5. Ship Systems
6. Space Systems
7. Surface Vehicle Systems

The work breakdown structure is a fundamental tool for effective project management. Part of this research to assess the relative effectiveness of the knowledge acquisition techniques was the development of an expert system to assist the development of a project work breakdown structure. However, since the expert system was not the goal of this research, the expert system produced during the course of this research is a limited prototype.

IV. Results and Findings

Overview

This chapter presents the results of the evaluation of the three knowledge acquisition techniques: the interview, concept mapping, and interruption analysis. The results of this quasiexperiment are broken down into three parts: technique implementation, rule and fact production, and expert system validation.

General Comments

This experiment attempted to evaluate one complicated facet of the expert system development process. Several of the fundamental steps necessary to execute the evaluation of the knowledge acquisition techniques are provided in the methodology and not in this chapter. This was not done because these particular steps are less important or easier than the evaluation of the knowledge acquisition techniques. On the contrary, each step was vitally important to the success of this evaluation. This chapter is reserved specifically for the results of evaluating the knowledge acquisition techniques. The reader is encouraged to review the process of task selection, the selection of experts, and the selection of the techniques to be evaluated presented in Chapter III. Much of this work is also supported by the literature reported in "An Introduction to Expert Systems and Knowledge Acquisition Techniques" (9).

Technique Implementation

The results presented in this section refer to that portion of this experiment that dealt with executing each of the knowledge acquisition techniques. It includes preparation time, the time spent interacting with the expert, and the time it took to translate the initial knowledge into a form that could be used for rule and fact generation.

Knowledge Acquisition Technique Implementation. As the reader will recall, each knowledge acquisition session was scheduled for approximately one hour. In addition to the actual time spent interacting with the experts, the time spent transcribing and integrating information from the audiotapes and other sources, as well as the total time involved in preparing for each technique was recorded. Table 1 presents the results of this phase of the evaluation. These results show that the interview technique took the least amount of time (419.1 mins), followed by interruption analysis (505.4 mins), and concept mapping (630.0 mins). These total times disguise the true time consuming factor, that being the transcription times. Both the interview and interruption analysis had comparable transcription times, yet the concept mapping took almost twice as long to transcribe as the other two techniques. The transcription times account for 49% of the total interview time, 42% of the total interruption analysis time

Table 1.
Knowledge Acquisition Technique
Implementation Times*

	Interaction Times	Transcription Times	Preparation Times	Total Time
Interview	181.4	205.0	32.0	419.1
Concept Mapping	166.0	404.0	60.0	630.0
Interruption Analysis	188.8	211.3	105.3	505.4

* All times in minutes.

and 64% of the concept mapping time. It should be noted, however, that the audiotapes of the interviews were not transcribed "word-for-word." Detailed notes of the interview tapes were prepared in place of the "word-for-word" transcript. Appendix A provides a sample of a "word-for-word" transcription of a portion of one interview. If the interview tapes had been transcribed "word-for-word," considerably more time would have accumulated during the transcription portion of this test.

The preparation times show a variation of 75 minutes between the two extremes. The interview preparation time consisted of identifying questions to start each interview session. The majority of this time occurred before the first interview, with subsequent questions arising during the transcription of the interview tapes. The preparation time for the concept mapping was spent teaching the expert about the concept mapping technique, and having the expert

generate some unrelated practice concept maps. Questions used during the actual concept mapping sessions were generated as individual maps were drawn. For the interruption analysis, the preparation time was spent identifying and developing two case studies. One case study was available from the AFIT Acquisition and Planning SYS 200 course text (AFIT/LS). The second case study was developed by this researcher and accounts for the bulk of this preparation time.

Rule and Fact Production

This portion of the evaluation examined five different criteria as quantitative measures of effectiveness for each knowledge acquisition technique. These quantitative measures were:

1. The time required to formulate rules;

2. The total number of rules generated;

3. The number of inferences necessary to complete rules;

4. An examination of the different knowledge sets to determine the contribution each knowledge acquisition technique made to the final expert system developed during the course of this research; and

5. The number of translations necessary to convert the expert knowledge into reasonably correct expert system rules.

In addition to these quantitative measures, each knowledge acquisition technique was rated on the ease with which the data could be translated into expert systems rules.

<u>Rule Formulation Times</u>. Rule formulation time was measured because time is a valuable resource for the knowledge engineer, and all things being equal, the technique that allowed the quickest formulation of rules would be considered the more desirable knowledge acquisition technique. For this measure, the work breakdown structure development process was divided into three relatively discrete portions, the first dealing with the program hardware, the second dealing with elements referred to as "other contract costs," and the third dealing with "other government costs." A random number generator was used to match each knowledge acquisition technique to a particular portion of the work breakdown structure process. Then, three production rules were generated from each knowledge data set for the portion of the work breakdown structure process to which it was matched. A production rule is a rule that follows the "If-Then" format, but in a narrative form that does not necessarily match the syntax required for the expert system software.

> IF: This is a development work breakdown structure, AND other contract costs are to be considered, AND Air Force experience with this prime mission equipment is limited;

THEN: Type 1 Training should be included as a level 2 work breakdown structure element of the Full-Scale Development work breakdown structure.

The times required to formulate each rule are recorded in Table 2.

Table 2.
Rule Formulation Times*

Rules	First	Second	Third	Total	Average
Interview	8.43	2.22	2.67	13.32	4.44
Concept Mapping	3.42	2.22	2.67	8.31	2.77
Interruption Analysis	4.53	7.67	5.70	17.90	5.97

* All time in minutes

Clearly, concept mapping required the least time to formulate production rules for an expert system. Also, concept mapping demonstrated the least variation in time for its three rules among the three techniques. One could argue that the interview total was skewed because of the time required for the first rule. This time resulted from having to search through all of the interview material to find references for the pertinent portion of the work breakdown structure process. While it appears that the subsequent formulation times approach those of the concept map, searching for the unrelated bits of information collected by the interview technique could be expected to increase times as more complex rules were formulated. Additionally, a longer initial search time to identify pertinent data could

be expected each time a different portion of the work breakdown structure process was attempted.

Rule Formulation and Inferences Required. The number of rules formulated and the inferences required to formulate those rules were measured because experts are typically very busy individuals and as such, it is better to acquire more pertinent knowledge per unit of interaction time. Additionally, the fewer the inferences the knowledge engineer is required to make, the more accurately the expert system rule base will reflect the expert's knowledge. Again, the work breakdown structure process was separated into three discrete portions as was done for the previous test. A random number generator was used to select one of these three discrete portions. All of the rules possible were generated for this one portion using the knowledge collected with each of the three knowledge acquisition techniques. As the rules were formulated, the number of inferences required to complete a rule were noted. Unlike the previous test, the knowledge collected by all three techniques was evaluated using the same portion of the work breakdown process. Table 3 illustrates the results from this test.

Interruption analysis provided the greatest number of rules for this portion of the work breakdown structure. Concept mapping and interviewing provided virtually the same number of rules. Of course, this analysis does not imply

Table 3.
Number of Rules Formulated
and Inferences Required to Formulate Rules

	Number of Rules	Number of Inferences
Interview	15	7
Concept Mapping	16	1
Interruption Analysis	20	13

that with subsequent interviews or concept mapping sessions, additional rules could not be generated. Given the fixed and somewhat limited time, interruption analysis proved superior for rule generation.

Concept mapping required the fewest inferences to complete its set of rules. Interruption analysis required the greatest number of inferences because there was little explanation provided for the actions that the expert took unless something was done that the investigator clearly did not understand. Otherwise, the investigator assumed certain rationales for certain actions. As a consequence, the knowledge gained by this technique was implied by the expert's actions rather than verbally explained. The results from this test reflect the fact the investigator made assumptions about rules for instances when he did not ask the expert the exact reason for the expert's action.

Differences in Knowledge Collected. When acquiring expert knowledge, it is important to access the breadth and depth of an expert's knowledge about a given task. This test attempted to determine if any of the techniques missed whole blocks of knowledge important to developing a work breakdown structure. The next test is a measure of the differences in the knowledge collected by the three knowledge acquisition techniques. For the first test, the composite knowledge collected by each technique was divided into four general areas. "Background information" relates to information about the work breakdown structure. This includes the purpose of the work breakdown structure, organizations within a program office that may use a work breakdown structure, and some of the terminology associated with the work breakdown structure. "WBS Format" refers to the accepted format of the printed work breakdown structure for any particular project or program. "Differences in WBSs" addresses the differences between the production and development work breakdown structures. Lastly, "WBS Elements" refers to knowledge about individual elements of the work breakdown structure at either the task (level 2) or sub-task (level 3) level.

As Table 4 depicts, the interview method addressed each of these areas. Concept mapping failed to address proper formatting of a work breakdown structure, and interruption

analysis provided no background information about the work breakdown structure.

Table 4.
Overview of the Knowledge
Collected Using Each Technique

	Background Information	WBS Format	Differences in WBSs	WBS Elements
Interview	YES	YES	YES	YES
Concept Mapping	YES	NO	YES	YES
Interruption Analysis	NO	YES	YES	YES

Next, a prototype expert system was developed. The knowledge collected using all three techniques was integrated into a complete knowledge base of the work breakdown structure process. This aggregate knowledge base was then used to create an expert system. Subsequent measures of the relative effectiveness of the three knowledge acquisition techniques were done using this prototype expert system. The code for this expert system car be found in Appendix B.

The second measure of the differences in the knowledge collected was to assess the contribution each technique made to the aggregate expert system. This was done after the prototype expert system was complete and before the system was validated.

Each rule of the expert system was evaluated to determine if it could have been created from the knowledge collected from each technique. The expert system's seventy-nine rules were divided into the general areas addressing hardware, other contract costs (OCC), and other government costs (OGC). Each of these areas was further divided into rules addressing either the project level (Level 1), task level (level 2) or the sub-task level (level 3). Table 5 illustrates the results of this test.

Table 5.
Number of Rules Contributed to the Aggregate Expert System By Each Knowledge Acquisition Technique

	Interview	Concept Map	Int. Analysis
Hardware			
Level 1			
Rule 10			X
Rule 20			X
sub-total	0	0	2
Level 2			
Rule 30	X	X	X
Rule 40			X
Rule 240			X
sub-total	1	1	3
Level 3			
Rule 50			X
Rule 60			X
Rule 70			X
Rule 80	X	X	X
Rule 90			X
Rule 100			X
Rule 110			X
Rule 120			X
Rule 130			X
Rule 140			X
Rule 150			X
Rule 160			X

Table 5 continued

	Interview	Concept Map	Int. Analysis
Rule 170	X	X	X
Rule 180			X
Rule 190			X
Rule 200			X
Rule 210			X
Rule 220			X
Rule 230			X
Rule 250			X
Rule 260			X
Rule 270			X
Rule 280			X
Rule 290			X
Rule 300			X
Rule 310	X	X	
Rule 320	X	X	
Rule 330	X	X	
sub-total	5	5	25
Other Contract Costs			
Level 2			
Rule 340	X	X	
Rule 350	X	X	X
Rule 360	X	X	X
Rule 410	X	X	
Rule 420	X	X	X
Rule 460	X	X	X
Rule 510	X	X	X
Rule 520	X		
Rule 530	X	X	X
Rule 540	X	X	X
Rule 570	X		X
Rule 600	X	X	
Rule 610		X	
Rule 620	X	X	
Rule 630	X	X	
Rule 640	X	X	
Rule 650	X	X	
Rule 660	X	X	
Rule 670	X	X	
Rule 680	X	X	
sub-total	19	18	8
Level 3			
Rule 370			X
Rule 380			X
Rule 390			X

Table 5 continued

	Interview	Concept Map	Int. Analysis
Rule 400			X
Rule 430			X
Rule 440			X
Rule 450			X
Rule 470		X	X
Rule 480		X	X
Rule 490			X
Rule 500		X	X
Rule 550		X	X
Rule 560		X	X
Rule 580			X
Rule 590			X
sub-total	0	5	15
Other Government Costs			
Level 2			
Rule 690	X	X	
Rule 700	X	X	
Rule 710	X	X	
Rule 720	X	X	
Rule 730	X	X	
Rule 740	X	X	
Rule 750	X	X	
Rule 760	X	X	
Rule 770		X	
Rule 780	X	X	
Rule 790	X	X	X
sub-total	10	9	1
total	35	38	54

Clearly, interruption analysis provided the greatest number of rules overall (68% of the total) and for the more detailed level 3 work breakdown structure elements. Interviewing and concept mapping provided results similar to each other (44% for the interview and 48% for concept mapping), focusing on the task or level 2 work breakdown structure elements associated with other contract costs and

other government costs. The reader is reminded that these rules may have required inferences to complete the formulation of the rule. As the reader will recall from the "Rule Formulation and Inferences Required" portion of this analysis, interruption analysis required inferences when formulating 65% of its rules, interviews required inferences for 47% of its rules, and concept mapping required inferences for 6% of its rules.

Number of Knowledge Transformations. The more changes required to produce an expert system rule, the more time it will take the knowledge engineer to create an expert system rule base, and the greater the possibility for interpretation errors or errors of omission. Thus, fewer transformations of knowledge would be preferred. The transcribing of knowledge has been discussed in the section entitled "Technique Implementation." The number of knowledge transformations, however, refers to the number of changes the knowledge must undergo to become an expert system rule with proper syntax.

For example, detailed notes from an interview audiotape may have yielded the following:

> ...MIL-STD-881 does not address differences between a production and a development work breakdown structure. For instance, software and software integration are common work breakdown structure elements, but software development should be completed during program development. As such, no software elements should appear in the production work breakdown structure.

These notes represent one transformation of the knowledge: tape to notes. The next transformation would create the production rule from the notes. A production rule puts the knowledge in the following form:

> IF: This is a development work breakdown structure, and computer programs are used by the program hardware
>
> THEN: Hardware/Software Integration should be included as a level 3 work breakdown structure element under Hardware.

This production rule represents the second transformation for the expert's knowledge. The third and final transformation of the knowledge would be the translation of the production rule into the proper expert system syntax:

```
IF:    WBS_type=development AND
       computer_programs=yes

THEN:  level_3=Hardware_Software_Integration
```

The steps involved in preparing an expert system rule for the interview included transferring the knowledge from the audiotape to a written format; producing a production rule from the written text; then producing an expert system rule.

Concept mapping involved the same steps. However, instead of detailed notes of the audiotapes, concept maps were produced. Production rules were then created from the concept maps, and finally, an expert system rule was encoded.

Interruption analysis involved the fewest number of knowledge transformations. Since verbal information was exchanged only when the investigator did not understand an action, the audiotapes of these sessions provided no really new information. The investigator was able to collect all of the necessary information in written form, even when questions were asked. For interruption analysis, transformation of data consisted of forming production rules from written notes and then translating the production rules into the proper syntax for the expert system software. Table 6 presents a summary of the numerical data from this test.

Table 6.
Number of Knowledge Transformations
Necessary to Create an Expert System Rule

	Interview	Concept Mapping	Interruption Analysis
Transformations Required	3	3	2

Expert System Validation. The most important test of any knowledge acquisition technique is how well the resulting expert system reflects the expert's knowledge. The technique that causes the fewest knowledge base errors would be the better knowledge acquisition technique. As a final measure of these knowledge acquisition techniques, a limited prototype expert system was developed integrating the information collected from all three knowledge

acquisition techniques. This expert system was then taken back to the participating experts to determine if these techniques could aid the development of an expert system that accurately produced a work breakdown structure.

To validate the expert system, the experts were asked to construct an appropriate work breakdown structure using a fictional case study. The work breakdown structure was constructed using the prototype expert system. The expert's were asked to carefully analyze the system's output as well as the decision rules of the expert system.

Discrepancies were noted and then analyzed to determine the nature of the errors. Generally, errors were assumed to be the result of incomplete information resulting in faulty inferences, errors in the actual knowledge conveyed to the expert system programmer, or errors that resulted from mistakes in expert system programming.

The first expert, who was the subject for the interviews, identified six discrepancies in the expert system execution. All of the discrepancies related to differences between the development and production work breakdown structures. Five of these discrepancies resulted from insufficient information received during the knowledge acquisition sessions. In each case, the decision rule was correct for the development work breakdown structure, but incorrect for the production work breakdown structure. Of these five incorrect rules, four of the rules had been

addressed during the interview sessions and one had not. Even though information pertaining to the four rules had been provided by the expert, this information was not sufficiently clear to prevent an error in its encoding. The other inference error resulted when the investigator encountered a specific work breakdown structure element that had not been addressed during the interview sessions. These five errors were determined to be attributable to the knowledge acquisition technique.

In the remaining case, the expert felt that instead of automatically including a particular work breakdown structure element, a question requiring user input should be used to decide if the element should be included. This discrepancy was the result of conflicting information received by the investigator from the experts.

The second expert, who was the subject for the concept mapping sessions, noted only two discrepancies. One error was the same as that identified by the first expert and involved a difference between a development and a production work breakdown structure. As with the first expert, this error was attributed to an incorrect inference on the part of the investigator and judged to be attributable to the knowledge acquisition technique. This area had also been addressed during the initial concept mapping sessions. The second error involved a difference in the knowledge between two of the experts. One expert who had contributed to the

knowledge base felt a particular element of the work breakdown structure was distinct, yet this expert felt that the element was not distinct, merely synonymous with a second work breakdown structure element and should not be included as an element in a work breakdown structure.

The third expert, who was the subject for the interruption analysis technique, identified three discrepancies. One discrepancy dealt with which particular level a certain work breakdown structure element should be found in. This discrepancy was attributed to a difference in the expert's knowledge. This expert also noted that the work breakdown structure element "data processing equipment" appeared only in the production version of the work breakdown structure when it should have appeared in the development version also. Upon investigation, it was discovered that the expert system had prompted the expert about this element for the development work breakdown structure, but the expert had neglected to include this element when asked the first time. The expert system was not at fault. On another topic, this expert also felt that one rule regarding missile system propulsion should be added. This last error was determined to be a programming error on the part of the investigator. The method that the investigator used to program this particular section allowed a correct element to be included, but the expert felt the decision rule was not adequate to elicit a proper response

from a system user. Neither of the other two experts noted the problem.

General Observations

Technique Implementation. The numerical data does not reflect all the pertinent information relative to technique implementation. There are a number of general observations that are important.

First, this researcher felt that interviews were the easiest technique to use, followed by interruption analysis, and lastly concept mapping. This was due to the fact that the interview required little preparation, and transcription of the interview tapes was not complicated. If the entire interview had been transcribed "word-for-word," the interview would have been considerably more difficult than either of the other two techniques.

Second, the expert who participated in the concept mapping technique was not comfortable with this format. The expert experienced a great deal of difficulty with the propositional linkages, and trying to find an appropriate proposition proved time consuming and distracting. To help the flow of information, and put the expert more at ease, the concept maps were de-emphasized during the sessions. Smaller concept maps were drawn or simple lists were generated. This researcher then integrated these smaller maps and lists into a larger map that provided the basis for the following sessions.

Lastly, if it were not for having to develop case studies for the interruption analysis, this technique would have been the easiest to implement. Watching the expert perform a task was all the catalyst necessary to generate questions and convey information.

Rule and Fact Production. The numerical data presents a fairly accurate picture of the relative effectiveness of the three techniques in rule and fact production. The graphical representation of knowledge as provided by the concept mapping technique proved the easiest method to use for drafting production rules. Appendix C represents the concept map that resulted from the three knowledge acquisition sessions. Not only were the relationships clear and concise, but the concept map required the least amount of time to search and find all of the pertinent relationships.

The most difficult knowledge to work with was that of the interview. This data was only loosely structured, and as such required a good deal of effort to identify pertinent information and then deduce important relationships within that information.

While the knowledge collected using interruption analysis provided the greatest number of production rules, it also required the greatest number of inferences. Even though this knowledge was very process oriented, it suffered

some of the same disorganization as the information collected from the interview.

Even though interruption analysis required the greatest number of inferences, validation of the expert system indicated that interviews allowed the greater number of inaccuracies in the expert system rule base. While the expert system represented a composite of all the knowledge collected, the errors identified by the interviewed expert, with one exception, were specific to knowledge collected during the interview sessions.

Summary

The findings presented in this chapter attempted to identify differences in the relative effectiveness of the three tested knowledge acquisition techniques. Each technique was evaluated using criteria pertinent to implementing the technique, and each was evaluated relative to the rules and facts produced. Technique implementation examined interaction time, transcription time, and preparation time. Rule and fact production examined the time to identify rules within the expert knowledge, the number of rules generated, the number of inferences required to generate those rules, general differences in the knowledge collected, the percentage of rules each technique contributed to the aggregate prototype expert system, and the number of transformations of the knowledge required to make an expert system rule.

V. Recommendations

Research Review

Knowledge acquisition presents a challenging aspect of expert system development for the knowledge engineer. Review of existing expert system and artificial intelligence literature provided little useful information about deciding which knowledge acquisition technique or techniques would be the most effective for a given task. It was the purpose of this research project to evaluate the relative effectiveness of three knowledge acquisition techniques for developing an expert system to produce a project work breakdown structure.

Conditions and Recommendations

There are a number of conclusions that can be drawn from this study. Perhaps the most obvious conclusion is that no one technique is clearly superior for developing a work breakdown structure expert system under all the conditions that a knowledge engineer may encounter. However, if the knowledge engineer is faced with certain conditions surrounding the project, then a distinct order of effectiveness among the techniques becomes evident.

Before specific conditions and recommendations are provided, the reader should remember the following:

-The results of this experiment pertain only to developing an expert system to produce a project work

breakdown structure and may not be appropriate for other tasks.

-One of the techniques evaluated in this experiment, interruption analysis, requires a task that can be observed.

For the reader's convenience, Table 7 provides a review of the data collected during this research. Table 7 provides the totals or averages for each of the quantitative measures used to evaluate each knowledge acquisition technique's relative effectiveness.

The recommendations of this research are the result of evaluating each technique according to three general characteristics. The first characteristic is that of the quality of the knowledge extracted. Quality includes the accuracy and completeness of the knowledge. The second characteristic is that of the time required to exercise each technique. Project time constraints may impose limitations on either the knowledge engineer, the expert, both, or neither individual. The third characteristic is the quantity of the knowledge collected. Quantity includes the breadth of the knowledge elicited and the number of expert system rules created. Each of the following recommendations is preceded by conditions that the knowledge engineer may face when acquiring expert knowledge.

Table 7.
Summary of Research Data

Test	Interview	Concept Mapping	Interruption Analysis
Implementation Times (totals)	419.1 m	630.0 m	505.4 m
Rule Formulation Times (average)	4.4 m	2.8 m	6.0 m
Number of Rules (for a specific part of the expert system)	15	16	20
Number of Inferences Required to Encode Previous Rules	7	1	13
Areas of Incomplete Knowledge	none	WBS format	Background
Number of Rules Contributed to the Expert System	35	38	54
Number of Knowledge Transformations	3	3	2
Number of Errors Created in the Expert System Knowledge Base	5	1	0

Conditions and Recommendation 1:

IF no time constraints are imposed on either the knowledge engineer or the project expert (optimal conditions)--

AND IF a large number of rules is a high priority--

AND IF the accuracy of the knowledge is a high priority--

AND IF breadth of knowledge is a high priority--

THEN a combination of concept mapping and interruption analysis would be the acquisition technique of choice.

This combination of techniques provided the broadest range of knowledge, the most expert system rules, and the fewest expert system errors. Since few knowledge engineers encounter optimal conditions, especially in the areas of their own time or the time of the experts whose knowledge they need, other acquisition techniques or combinations of techniques may be needed, as described below. Nonetheless, if the situation permits the combination of concept mapping and interruption analysis, the results should be a large number of accurate rules.

Conditions and Recommendation 2:

IF time is constrained for either the knowledge engineer or the project expert--

AND IF a large number of expert system rules is a high priority--

AND IF the accuracy of the knowledge is a high priority--

AND IF breadth of knowledge is a low priority--

THEN interruption analysis would be the acquisition technique of choice.

Interruption analysis provided the most expert system rules and fewest expert system errors. In addition, interruption analysis did not require the greatest amount of implementation time. Although encoding expert system rules from the interruption analysis notes takes slightly longer than is necessary when encoding from interview notes or

concept maps, this liability is offset by the fact that interruption analysis produced 42% more expert system rules than the next best technique.

Conditions and Recommendation 3:

> IF the knowledge engineer has a limited understanding of the task for which the expert system is being developed--
>
> AND IF the accuracy of the knowledge is a high priority--
>
> AND IF the knowledge engineer has only limited time to spend with the project expert--
>
> THEN concept mapping would be the acquisition technique of choice.

Concept mapping provided sufficient breadth of knowledge, more expert system rules than the interview, fewer expert system errors than the interview, and quicker rule encoding than either interviews or interruption analysis. Concept mapping also required the least amount of interaction time with the expert.

Conditions and Recommendation 4:

> IF there are overall project time constraints--
>
> AND IF the knowledge engineer does not have a great deal of time to prepare for the knowledge acquisition sessions--
>
> AND IF the accuracy of the rules is not a high priority--
>
> THEN interviews would be the acquisition technique of choice.

Interviews required the least preparation time and the least overall implementation time, and provided a number of

rules comparable to concept mapping. However, interviews also created the most expert system errors. While interviews do have limitations, interviews can be useful in developing a prototype expert system to test the feasibility of the project.

Recommendations for Further Research

A great deal of additional research remains to be done in the areas of knowledge acquisition and the application of expert system technology. In general, there are at least three areas with the potential for follow-on research to this project.

First, there are a number of other knowledge acquisition techniques that this investigator did not evaluate. Additional experiments similar to this one, examining different combinations of knowledge acquisition techniques, could be used to evaluate the relative effectiveness of other techniques such as repertory grid analysis, protocol analysis, hierarchical clustering, questionnaires, and multidimensional scaling. These experiments may identify knowledge acquisition techniques or combinations of techniques that are more effective than those evaluated by this research.

Second, the same three knowledge acquisition techniques evaluated by this research could be tested using an experiment similar to this one but with a different problem domain and task to see if similar results could be obtained.

An experiment or series of experiments may identify one or a specific combination of these knowledge acquisition techniques as being generally more effective across a broad assortment of problem domains, tasks, and project conditions.

Third, the reader is reminded that a prototype expert system was developed during the course of this research. While this expert system was limited in its capability, it does provide a starting point from which a more functional expert system could be developed.

Summary

As stated earlier, the purpose of this study was to evaluate the relative effectiveness of the three knowledge acquisition techniques: interview, concept mapping, and interruption analysis. While no empirical evidence existed in the literature to assist this researcher in his choice of appropriate knowledge acquisition techniques for this experiment, the three techniques selected proved to be useful for developing a work breakdown structure expert system. Quantitative measures were developed to assess the relative effectiveness of these three knowledge acquisition techniques. These measures addressed such issues as the implementation of the technique, the analysis of the resulting knowledge, the contribution each technique made to the final expert system, and the number of errors in the final expert system attributable to the knowledge

acquisition technique. The results of this experiment indicated that under optimal expert system development conditions, a combination of techniques employing concept mapping and interruption analysis would be the most effective choice. While no one technique was identified as being clearly superior for all the possible conditions a knowledge engineer may encounter, the strength of this experiment is that it empirically identifies important strengths and weaknesses of each knowledge acquisition technique, and conditions where each technique or a specific combination of techniques is a better choice than others.

Appendix A: Sample of a "Word-for-Word" Transcription of an Interview

The following is a sample "word-for-word" transcription of a portion of one interview session. It represents about 9.6 minutes of interview content, and is intended to illustrate the effort required to transcribe an interview. This transcript took about 69 minutes to transcribe. This is approximately a 7 to 1 ratio of transcription time to actual interview tape content.

Investigator: Let's talk about the WBS process. And to that extent, I'm going to let it free-wheel. Basically, we'll treat this as a student-teacher relationship. I want you to...to teach me the process of developing a WBS in terms of RW's use. In as general terms as you can for right now. I will go home and analyze the data and generate more specific questions.

Expert: Ah....Of course MIL-STD-881 is where it starts. So, 881 should be in the background of everybody's thinking as they are doing this. Ah...ACCM's desire or what they are willing to sign off on should be the next screen we consider. ACCM is...is primarily concerned about getting us to...develop and get on contract WBS's that will produce data that will reasonably easily fit into OSD CAIG and AF CAIG data bases. Ah...the next thing we have to take into consideration is the real program. Many times...ah, when we do WBSs here, we are doing it with junior level analysts and many times junior level program managers and a fair amount of time...ah, occasionally I'd say, put it that way, junior level engineers. So we are usually dealing with a fairly green team.

When we start to develop a WBS,...the analysts, the cost analyst, usually takes the lead...ah, at least from my perspective...usually takes the lead because we deal with WBS on many different programs so we have a better feel for them across the board than the program manager who deals with it...perhaps, once in a lifetime or maybe twice.

Now here again, guide me if I'm not going down the right path.

We normally look at 3 major categories of stuff. Well, let me back off for a second... The program we are concerned first...about development, production and O&S. Okay,....

Investigator: And O&S is?

Expert: Operation and support. So,...ah, normally when we go on contract, we are going on for some or all of this. The instant contract is usually for development effort, and maybe with some priced options. Rarely do we have any O&S on contract yet. From ah, an ACCM perspective, they want to see a WBS...like that... And then they sa..., you know...In other words, they are concerned with the development program, and then later they are concerned with the production program. Okay, in talking with __________, he said when you come back with a...when you get ready to have another major contractual action you need to bring him another WBS for that effort, or show him how the one he previously approved has been revised. Ah, in talking off the record, I said gee, I've never worked a program that ever brought another WBS back through you. He said well, he can't be the policeman for all of ASD, he says they are supposed to. He says rarely do they, but they are supposed to.

Ah, development though, breaks down into prime mission equipment, OCC-other contractor costs, and other government costs. So we know that there is a family of things under each of those, but this is really the big question mark.

Investigator: The prime mission equipment?

Expert: Yes. The PME itself breakdown typically in one of two ways. It either breaks down directly into what we call hardware, software, or hardware/software integration effort...or it will breakdown into...a major segment or segments with the integration of those segments together. And each of those having hardware, software, and stand-alone integration and again hardware, software...I'm going to give you these drawings so you can relate to them later.

Okay, from _________'s perspective, I'll keep going back to that because he is our local interpreter of MIL-STD-881. He wants to see the...equipment at a reasonably high level. He wants to avoid breaking the details down to low. Um...his contention is on that one that...the lower level we specify...that's the lower level that the contractor needs to issue work authorization packages out to...out to his, what?...functional representatives. Okay, I guess they got to write up...ah, sell orders or something like that. Each contractor calls it something different.

Okay, going down this path, the hardware will generally breakdown into specific line replaceable units or what we like to consider...roughly line replaceable units. In some cases we have wierd stuff and it doesn't really breakdown that way. Those are the black boxes we are trying to estimate. And, software breaks down into CPCIs, or computer program configuration items.

By putting what _______, what ACCM calls a false summing level here, we force these down another level. Okay, so if _______ says here that this is the development program...which is different from that program, this is the development program is the only WBS he wants to look at...at one time. If the development program which is level one. That's a confusion factor that...ACCM is locked on real tight. Ah, my recommendation is because of what...of what can appear at one level depending upon how you've drawn the WBS, the exact same LRU can be at level 3, 4, or 5. Just based on how many false summing levels you put in there. If this program is level 1, level 2, level 3, that gets the LRU's at level 4.... Okay, if we get rid of this, move all this stuff up, then they have moved up to level 3 where __________ would really like to see them. Which means that on that path, we really have, there is PME, just replicating that PME level there. You have hardware item, hardware, hardware, hardware, integration of the hardware. Software, software, software, integration of the software. And then hardware-software integration. And that puts it back up at...the LRUs, or the ah, lowest level we go to is now at level 3. That's truly a confusion factor. This is the direction I'm trying to drive because it is what ACCM is looking for, and more closely replicates 881.

Investigator: That's what I've heard reference to as dummy levels basically?

Expert: Yes...Dummy levels or false summing levels. They are real handy you know...for us. And ah, something that is important is that ah...financial managers here at RW and a couple other SPO's are the ones who really put out the official WBS. And they do that via a form called the Systems Command SCIPS. AFSC Form 126. We're developing a WBS for our purposes, and that's to do a cost estimate. They are the ones who should be doing a WBS that gets it through the __________'s of the world. Generally speaking though, they have not thought about it to the extent, that, I don't know, they just use what we have. The first five attempts they will try to use exactly what we have. Then it starts to sink in because then that's where we get drug into it, like we did on the ______. We've worked with the WBS here in the Cost Shop. We know what it is, and we know how to get rid of some false summing levels, so we can more rapidly make, help them get a WBS that ACCM will buy...

Appendix B: Expert System Knowledge Base

The knowledge base created as the result of this experiment can be found on the following pages. VP Expert was the expert system shell that was used. The knowledge base is printed in its entirety and has been field tested as stated in the text of this report. No identified discrepancies have be corrected in this version.

Captions have been inserted within black boarders to explain some of the required syntax for developing a knowledge base for an expert system. The reader is reminded that the syntax used is specific to the VP Expert expert system shell.

ACTIONS: Identifies and begins the series of rules and user prompts that make up the expert system consultation. (13:9.2)

```
ENDOFF;

RUNTIME;

ACTIONS

DISPLAY"
Welcome to an experimental expert system to aid the
development of a draft work breakdown structure.  This
system is limited to the ELECTRONICS or MISSILE categories
of defense materiel items.  Please feel free to experiment
with this system, but, recognize that it is  limited in
capability.  Much additional research is needed to make this
system fully functional.

To answer the questions presented by this expert system,
either input an appropriate name when asked, or if the
question can be answered by the yes or no menu, use the
arrow keys and the enter key to indicate your  response.  An
unknown answer (indicated by a '?' mark) to any 'Yes or No'
question will be treated as a 'No'.   That particular
element will be left  off the final work breakdown
structure.

Please strike any key to continue the consultation.~
"
cls

DISPLAY"

The expert system will present you with the work breakdown
structure element and the proper numbering of that element
on the monitor.  Additionally, the  expert system will also
cause the printer to print the element and number.

Please strike any key to continue the consultation.~
"
cls


CLS
X=0
Y=0
FIND      program
FIND      category
CLS
DISPLAY   "Your system belongs in the {category} CATEGORY of
defense materiel items.

Press any key to continue the consultation.~"

CLS
```

```
FIND        WBS_type
```

FIND: Identifies variables in the VP-Expert knowledge base that must be identified to complete a consultation. These variables may be identified through user inputs or from the execution of expert system rules. (13:9.43)

```
FIND        occ
FIND        ogc

CLS

PRINTON

DISPLAY     "1.{X}                {program} {WBS_type}"

FIND        product
FIND        level_3
FIND        producta
FIND        level_3
FIND        level_2

;
```

ASK: If the expert system inference engine cannot find a value for a variable identified in a FIND clause, an ASK clause can be used to prompt the expert system user for the variable value. (13:9.9)

```
ASK program: "What is the name of your acquisition
program?";

ASK WBS_type: "Do you wish to produce a draft work breakdown
structure for development (FSD) or for production?
";
ASK occ:"
Do you wish to include other contract costs in your WBS?
";
ASK ogc:"Do you wish to include other government costs in
your WBS?
";
```

CHOICES: Used in conjunction with an ASK statement to restrict the user's input to one or a combination of specific values for a given variable. (13:9.23)

```
CHOICES WBS_type: Development, Production;
CHOICES electronic, space_vehicle, sensors, comm1,
autodata, programs, displays, auxequip: YES,NO;
CHOICES guidance, payload, occ, ogc: YES,NO;
CHOICES shroud, testequip, trainequip, auxequip2,
surveillance,
launch_control, comm2: YES, NO;
CHOICES PMD, launch_equip, auxequip3, dataprocess: YES, NO;
CHOICES PMD1, PMD2, PMD3, experience, subcontractors,
other_software,
material, destination: YES,NO;
```

```
CHOICES PMD4, PMD5, PMD6, PMD7, value,new_tech, common,
command: YES, NO;
CHOICES TP, ED, MD, SD: YES,NO;
CHOICES E, S, F: YES, NO;
CHOICES DTE, OTE, mockups, tesupport: YES,NO;

RULE 10

IF        electronic=yes
THEN      category=ELECTRONICS;

ASK electronic:"
Is {program} classified as the electronics portion of a
defense materiel item AND is the system unique or used as a
building block for several systems not accounted for in
those systems?
";
```

RULE: A premise or series of premises and a conclusion. The conclusion is true only if the premises are satisfied. The conclusion can be used to assign values to variables. (13:9.85)

```
RULE 20

IF        space_vehicle=yes
THEN      category=MISSILE;

ASK space_vehicle: "
Does {program} employ an unmanned, self-propelled air/space
vehicle AND does this air/space vehicle navigate, penetrate
and produce a desired effect on selected targets?
";


RULE 30

IF        category=electronics
THEN      product=PME
          X=(X+1)
FIND      PME
DISPLAY   "1.{X}          {PME}";

ASK PME:  "
What is the name of your prime mission equipment?
";
```

DISPLAY: Used to display text to the expert system user. This text must be enclosed within the double quotation marks. (13:9.34)

```
RULE 40

IF        category=missile
THEN      product=air_vehicle
          X=(X+1)
FIND      air_vehicle
DISPLAY   "1.{X}          {air_vehicle}";
```

```
ASK air_vehicle:"
What do you wish to name the air vehicle element of
{program}?
";


RULE 50

IF          category=electronics AND
            sensors=yes
THEN        level_3=Sensors
            Y=(Y+1)
DISPLAY     "1.{X}.{Y}        {level_3}"
RESET       level_3;

ASK sensors:"
Does {PME} have equipment to detect and indicate terrain
features, the presence of military targets, or other natural
or man-made objects be means of energy emitted or reflected
by those objects?
";


RULE 60

IF          category=electronics AND
            comm1=yes
THEN        level_3=Communications
            Y=(Y+1)
DISPLAY     "1.{X}.{Y}        {level_3}"
RESET       level_3;

ASK comm1:"
Does {PME} have the means to receive or transmit messages of
data from one person or place to another?
";


RULE 70

IF          category=electronics AND
            autodata=yes
THEN        level_3=Automatic_Data_Processing
            Y=(Y+1)
DISPLAY     "1.{X}.{Y}        {level_3}"
RESET       level_3;

ASK autodata:"
Does {PME} have equipment consisting of input, storage,
computing, control, and output devices which use electronic
circuitry to automatically perform arithmetic and/or logical
operations by means of internally or externally controlled
programmed instructions? ";
```

```
RULE 80

IF          category=electronics AND
            WBS_type=development AND
            programs=yes
THEN        level_3=Computer_Programs
            Y=(Y+1)
DISPLAY     "1.{X}.{Y}           {level_3}"
RESET       level_3;

ASK programs:"
Does {PME}{program} contain programs and routines consisting
of a deck of punched cards, magnetic or paper tapes,
read-only memory units, or other physical medium containing
a sequence of instructions and data in a form suitable for
insertion into a computer and used to direct the computer
to perform a desired operation or sequence of operations?
";


RULE 90

IF          category=electronics AND
            displays=yes
THEN        level_3=Data_Displays
            Y=(Y+1)
DISPLAY     "1.{X}.{Y}           {level_3}"
RESET       level_3;

ASK displays:"
Does {PME} contain a visual presentation of processed data
by specially designed electronic or electromechanical
devices through interconnections with digital computers or
component equipments NOT to include line printers or punched
cards?
";


RULE 100

IF          category=electronics AND
            auxequip=yes
THEN        level_3=Auxiliary_Equipment
            Y=(Y+1)
DISPLAY     "1.{X}.{Y}           {level_3}"
RESET       level_3;

ASK auxequip:"
Does {PME} contain common or multi-usage equipments used to
augment the functional performance of several level 3
elements and which are NOT homogenous to the designated
level 3 elements?
";
```

```
RULE 110

IF          category=MISSILE AND
            product=air_vehicle
THEN        FIND stages;

ASK stages:"
How many separable propulsion stages does {air_vehicle}
have? (not to exceed 4)
";

RULE 120

IF          category=missile AND
            stages=1
THEN        level_3=Propulsion
            Y=(Y+1)
DISPLAY     "1.{X}.{Y}          {level_3}"
RESET       level_3;

RULE 130

IF          category=missile AND
            stages > 1
THEN        level_3=Stage_1
            Y=(Y+1)
DISPLAY     "1.{X}.{Y}          {level_3}"
RESET       level_3;

RULE 140

IF          category=missile AND
            stages >= 2
THEN        level_3=Stage_2
            Y=(Y+1)
DISPLAY     "1.{X}.{Y}          {level_3}"
RESET       level_3;

RULE 150

IF          category=missile AND
            stages >= 3
THEN        level_3=Stage_3
            Y=(Y+1)
DISPLAY     "1.{X}.{Y}          {level_3}"
RESET       level_3;

RULE 160

IF          category=missile AND
            stages >=4
THEN        level_3=Stage_4
            Y=(Y+1)
```

```
DISPLAY    "1.(X).(Y)          (level_3)"
RESET      level_3;


RULE 170

IF         category=MISSILE AND
           WBS_type=development AND
           programs=yes
THEN       level_3=Computer_Programs
           Y=(Y+1)
DISPLAY    "1.(X).(Y)          (level_3)"
RESET      level_3;

ASK programs:"
Does (program) contain programs and routines consisting of a
deck of punched cards, magnetic or paper tapes, read-only
memory units, or other physical medium containing a sequence
of instructions and data in a form suitable for insertion
into a computer and used to direct the computer to perform a
desired operation or sequence of operations?
";

RULE 180

IF         category=missile AND
           guidance=yes
THEN       level_3=Guidance_and_Control_Equipment
           Y=(Y+1)
DISPLAY    "1.(X).(Y)          (level_3)"
RESET      level_3;

ASK guidance:"
Does (air_vehicle) have the means for generating or
receiving guidance intelligence, conditioning that
intelligence to produce signals and generating appropriate
control forces?
";


RULE 190

IF         category=missile AND
           payload=yes
THEN       level_3=Launched_Payload
           Y=(Y+1)
DISPLAY    "1.(X).(Y)          (level_3)"
RESET      level_3;

ASK payload:"
Does (air_vehicle) have a means to produce a destructive
effect on the target at the terminal point of flight?
";
```

```
RULE 200

IF         category=missile AND
           shroud=yes
THEN       level_3=Payload_Shroud
           Y=(Y+1)
DISPLAY    "1.{X}.{Y}          {level_3}"
RESET      level_3;

ASK shroud:"
Does {air_vehicle} have a protective enclosure for
safeguarding its payload during the severe environments of
launch and flight?
";


RULE 210

IF         category=missile AND
           testequip=yes
THEN       level_3=Airborne_Test_Equipment
           Y=(Y+1)
DISPLAY    "1.{X}.{Y}          {level_3}"
RESET      level_3;

ASK testequip:"
Does {air_vehicle} have an exercise warhead that is suitable
for developmental firing?
";


RULE 220

IF         category=missile AND
           trainequip=yes
THEN       level_3=Airborne_Training_Equipment
           Y=(Y+1)
DISPLAY    "1.{X}.{Y}          {level_3}"
RESET      level_3;

ASK trainequip:"
Does {air_vehicle} have an exercise warhead that is suitable
for training?
";


RULE 230

IF         category=missile AND
           auxequip2=yes
THEN       level_3=Auxiliary_Equipment
           Y=(Y+1)
DISPLAY    "1.{X}.{Y}          {level_3}"
```

```
RESET      level_3;

ASK auxequip2:"
Does {air_vehicle} have additional equipment, that is
excluded from the other level 3 elements, but that
supplements or provides service to these other elements
WITHIN the air vehicle, {air_vehicle}?
";


RULE 240

IF         category=missile AND
           command=yes
THEN       producta=Command_and_Launch_Equipment
           X=(X+1)
DISPLAY    "1.{X}          {producta}"
RESET       Y;

ASK command:"
Does {program} have subsystems installed at a launch site or
aboard launch vehicles for mobile systems, required to
store, make ready, and launch {air_vehicle}, the air vehicle
of this missile system?
";


RULE 250

IF         category=missile AND
           producta=Command_and_Launch_Equipment AND
           surveillance=yes
THEN       level_3=Surveillance_and_Tracking_Sensors
           Y=(Y+1)
DISPLAY    "1.{X}.{Y}          {level_3}"
RESET      level_3;

ASK surveillance:"
Does {program} have sensors to support defensive missile
systems by maintaining surveillance against incoming targets
and providing the data required for targeting, launch,
midcourse guidance, and homing where such capability IS NOT
self-contained aboard the missile system, {air_vehicle}?
";


RULE 260

IF         category=missile AND
           producta=Command_and_Launch_Equipment AND
           launch_control=yes
THEN       level_3=Launch_and_Guidance_Equipment
           Y=(Y+1)
```

```
DISPLAY    "1.{X}.{Y}          {level_3}"
RESET      level_3;

ASK launch_control:"
Does {program} have the means to enable targeting of missile
air vehicles, to enable launch decisions to be made, and to
enable command to launch?
";


RULE 270

IF         category=missile AND
           producta=Command_and_Launch_Equipment AND
           comm2=yes
THEN       level_3=Communications
           Y=(Y+1)
DISPLAY    "1.{X}.{Y}          {level_3}"
RESET      level_3;

ASK comm2:"
Does {program} have the means to distribute intelligence
within the missile system?
";

RULE 280

IF         category=missile AND
           producta=Command_and_Launch_Equipment AND
           dataprocess=yes
THEN       level_3=Data_Processing_Equipment
           Y=(Y+1)
DISPLAY    "1.{X}.{Y}          {level_3}"
RESET      level_3;

ASK dataprocess:"
Does {program} have the means to condition data generated at
the launch site or aboard the launch vehicle of a system
employing mobile launch capability, or data received from
associated systems to accommodate the needs of launch and
guidance control?
";

RULE 290

IF         category=missile AND
           producta=Command_and_Launch_Equipment AND
           launch_equip=yes
THEN       level_3=Launch_Equipment
           Y=(Y+1)
DISPLAY    "1.{X}.{Y}          {level_3}"
RESET      level_3;
```

```
ASK launch_equip:"
Does {program} have the means to launch the missile from
stationary or mobile launch platforms?
";


RULE 300

IF          category=missile AND
            producta=Command_and_Launch_Equipment AND
            auxequip3=yes
THEN        level_3=Auxiliary_Equipment
            Y=(Y+1)
DISPLAY     "1.{X}.{Y}        {level_3}"
RESET       level_3;

ASK auxequip3:"
Does {program} have general-purpose ground equipment used to
supplement the various operational equipments of the
{producta}?
";


RULE 310

IF          category=electronics  OR
            category=missile
THEN        level_3=Hardware_Integration
            Y=(Y+1)
DISPLAY     "1.{X}.{Y}        {level_3}"
RESET       level_3;


RULE 320

IF          category=electronics OR
            category=missile AND
            WBS_type=development AND
            programs=yes
THEN        level_3=Software_Integration
            Y=(Y+1)
DISPLAY     "1.{X}.{Y}        {level_3}"
RESET       level_3;


RULE 330

IF          category=electronics OR
            category=missile AND
            WBS_type=development AND
            programs=yes
```

```
THEN        level_3=Hardware_Software_Integration
            Y=(Y+1)
DISPLAY     "1.{X}.{Y}          {level_3}"
RESET       level_3;


RULE 340

IF          WBS_type=development AND
            new_tech=yes
THEN        level_2=Precontract_Award_Studies
            X=(X+1)
DISPLAY     "1.{X}          {level_2}"
RESET       level_2;

ASK new_tech:"
Does {program} contain radical, state of the art, new
technology or does {program} represent a significant
up-grade to existing technology?
";


RULE 350

IF          WBS_type=development AND
            occ=yes
THEN        level_2=Sys_Engineering_and_Proj_Mgt
            X=(X+1)
DISPLAY     "1.{X}          {level_2}"
RESET       level_2;


RULE 360

IF          WBS_type=development OR
            WBS_type=production AND
            occ=yes
THEN        level_2=Data
            X=(X+1)
DISPLAY     "1.{X}          {level_2}"
RESET       Y
FIND        level_3d
RESET       level_2;


RULE 370

IF          level_2=data AND
            TP=yes
THEN        level_3d=Technical_Publications
            Y=(Y+1)
DISPLAY     "1.{X}.{Y}          {level_3d}"
RESET       level_3d;
```

```
ASK TP:"
Does (program) require the development of formal technical
orders/manuals for the installation, operation, maintenance,
overhaul, training and reference of hardware and computer
programs?
";


RULE 380

IF          level_2=data AND
            ED=yes
THEN        level_3d=Engineering_Data
            Y=(Y+1)
DISPLAY     "1.(X).(Y)          (level_3d)"
RESET       level_3d;

ASK ED:"
Does the Program Office want engineering drawings,
associated lists, specifications, and other similar
documentation?
";


RULE 390

IF          level_2=data AND
            MD=yes
THEN        level_3d=Management_Data
            Y=(Y+1)
DISPLAY     "1.(X).(Y)          (level_3d)"
RESET       level_3d;

ASK MD:"
Does the Program Office want those data items necessary for
configuration management, cost, schedule, contractual data
management, and program management?
 ";


RULE 400

IF          level_2=data AND
            SD=yes
THEN        level_3d=Support_Data
            Y=(Y+1)
DISPLAY     "1.(X).(Y)          (level_3d)"
RESET       level_3d;

ASK SD:"
Does the Program Office want those data items to document
the logistics support planning and provisioning process? ";
```

```
RULE 410

IF          occ=yes AND
            PMD2=yes
THEN        level_2=Data_Rights
            X=(X+1)
DISPLAY     "1.{X}          {level_2}"
RESET       level_2;

ASK PMD2:"
Does the PMD or the System Program Office indicate that data
rights are required?
";


RULE 420

IF          WBS_type=development OR
            WBS_type=production AND
            occ=yes
THEN        level_2=Training
            X=(X+1)
DISPLAY     "1.{X}          {level_2}"
RESET       Y
FIND        level_3t
RESET       level_2;


RULE 430

IF          level_2=Training AND
            E=yes
THEN        level_3t=Equipment
            Y=(Y+1)
DISPLAY     "1.{X}.{Y}          {level_3t}"
RESET       level_3t;

ASK E:"
Are distinctive items of training equipment needed to meet
specific training objectives?
";


RULE 440

IF          level_2=Training AND
            S=yes
THEN        level_3t=Services
            Y=(Y+1)
DISPLAY     "1.{X}.{Y}          {level_3t}"
RESET       level_3t;

ASK S:"
```

```
Are services, devices, accessories, and aids necessary to
accomplish training objectives?
";


RULE 450

IF          level_2=Training AND
            F=yes
THEN        level_3t=Facilities
            Y=(Y+1)
DISPLAY     "1.{X}.{Y}        {level_3t}"
RESET       level_3t;

ASK F:"
Are special constructions necessary to accomplish training
objectives?
(specifically brick and mortar type construction)
";


RULE 460

IF          WBS_type=development AND
            OLC=yes
THEN        level_2=System_Test_and_Evaluation
            X=(X+1)
DISPLAY     "1.{X}        {level_2}"
RESET       Y
FIND        level_3te
RESET       level_2;


RULE 470

IF          level_2=System_Test_and_Evaluation AND
            DTE=yes
THEN        level_3te=Development_Test_and_Eval
            Y=(Y+1)
DISPLAY     "1.{X}.{Y}        {level_3te}"
RESET       level_3te;

ASK DTE:'
Does {program} require tests to:

a)  Demonstrate that design risks have been minimized?
b)  Demonstrate that the engineering design and development
process is complete?
c)  Demonstrate that the system will meet specifications?
d)  Estimate the {pme}{air_vehicle}'s military utility?
e)  Provide test data with which to examine and evaluate the
tradeoffs against specification requirements, life cycle
cost, and schedule? ";
```

```
RULE 480

IF          level_2=System_Test_and_Evaluation AND
            OTE=yes
THEN        level_3te=Operational_Test_and_Eval
            Y=(Y+1)
DISPLAY     "1.{X}.{Y}           {level_3te}"
RESET       level_3te;

ASK OTE:"
Are tests to be conducted by agencies other than the
developing command to assess {program}'s military utility,
operational effectiveness, operational suitability,
logistics supportability, cost of ownership, and
need for any modifications?
";


RULE 490

IF          level_2=System_Test_and_Evaluation AND
            mockups=yes
THEN        level_3te=Mockups
            Y=(Y+1)
DISPLAY     "1.{X}.{Y}           {level_3te}"
RESET       level_3te;

ASK mockups:"
Is there a need to design and produce system or subsystem
mockups which have special contractual or engineering
significance, or which are NOT required solely for the
conduct of one of the above elements of testing?
";


RULE 500

IF          level_2=System_Test_and_Evaluation AND
            tesupport=yes
THEN        level_3te=Test_and_Evaluation_Support
            Y=(Y+1)
DISPLAY     "1.{X}.{Y}           {level_3te}"
RESET       level_3te;

ASK tesupport:"
Will contractor support be necessary to operate and maintain
systems during testing and evaluation which are NOT consumed
during a particular category of testing? Operator and
maintenance personnel, consumables, special fixtures,
special instrumentation, etc. which are used in a single
element of testing (such as DT&E) should not be included
under this element.
";
```

```
RULE 510

IF          WBS_type=production AND
            occ=yes
THEN        level_2=Sustaining_Eng_and_Proj Mgt
            X=(X+1)
DISPLAY     "1.{X}          {level_2}"
RESET       level_2;


RULE 520

IF          WBS_type=production AND
            occ=yes
THEN        level_2=Acceptance_Testing
            X=(X+1)
DISPLAY     "1.{X}          {level_2}"
RESET       level_2;


RULE 530

IF          occ=yes AND
            PMD=yes
THEN        level_2=Aircraft_Integration
            X=(X+1)
DISPLAY     "1.{X}          {level_2}"
RESET       level_2;


ASK PMD:"
Does the PMD or the System Program Office indicate that
aircraft integration is required?
";


RULE 540

IF          occ=yes AND
            PMD1=yes
THEN        level_2=Peculiar_Support_Equipment
            X=(X+1)
DISPLAY     "1.{X}          {level_2}"
RESET       Y
FIND        level_3PSE
RESET       level_2;


ASK PMD1:"
Does the PMD or the System Program Office indicate that
peculiar support equipment is required or is unique
equipment required to support and maintain {program} and
which has an application unique to {program}? ";
```

```
RULE 550

IF          OI=organizational OR
            OI=both
THEN        level_3PSE=Organizational_or_Intermediate
            Y=(Y+1)
DISPLAY     "1.{X}.{Y}          {level_3PSE}"
RESET       level_3PSE;


RULE 560

IF          OI=Depot OR
            OI=both
THEN        level_3PSE=Depot
            Y=(Y+1)
DISPLAY     "1.{X}.{Y}          {level_3PSE}"
RESET       level_3PSE;

ASK OI:"
Is the Peculiar Support Equipment required at the
organizational/intermediate, depot level or both?
";
CHOICES OI: Organizational, Depot, Both;


RULE 570

IF          ogc=yes AND
            common=yes
THEN        level_2=Common_Support_Equipment
            X=(X+1)
DISPLAY     "1.{X}          {level_2}"
RESET       Y
FIND        level_3c
RESET       level_2;

ASK common:"
Does {program} require additional support equipment that can
be identified through national stock number listings?
(input from a logistician recommended)
";


RULE 580

IF          OIc=organizational OR
            OIc=both
THEN        level_3c=Organizational_or_Intermediate
            Y=(Y+1)
DISPLAY     "1.{X}.{Y}          {level_3c}"
RESET       level_3c;
```

```
RULE 590

IF          OIc=Depot OR
            OIc=both
THEN        level_3c=Depot
            Y=(Y+1)
DISPLAY     "1.{X}.{Y}          {level_3c}"
RESET       level_3c;

ASK OIc:"
Is the Common Support Equipment required at the
organizational/intermediate, depot level or both?
";
CHOICES OIc: Organizational, Depot, Both;



RULE 600

IF          occ=yes AND
            experience=no
THEN        level_2=Type_1_Training
            X=(X+1)
DISPLAY     "1.{X}          {level_2}"
RESET       level_2;

ASK experience:"
Does the Air Force have experience with this type of weapon
system?
";


RULE 610

IF          occ=yes AND
            subcontractors=yes
THEN        level_2=Work_Measurement
            X=(X+1)
DISPLAY     "1.{X}          {level_2}"
RESET       level_2;

ASK subcontractors:"
Will the prime contractor employ subcontractors to help
fulfill the requirements for {program}?
";


RULE 620

IF          occ=yes AND
            WBS_type=development AND
            programs=yes
```

```
THEN        level_2=Software_Integration_Lab
            X=(X+1)
DISPLAY     "1.{X}          {level_2}"
RESET       level_2;

RULE 630

IF          WBS_type=development AND
            occ=yes AND
            programs=no AND
            other_software=yes
THEN        level_2=Software_Integration_Lab
            X=(X+1)
DISPLAY     "1.{X}          {level_2}"
RESET       level_2;

ASK other_software:"
Does {program} require software development for software
that will be critical for system flight operations?
";


RULE 640

IF          occ=yes AND
            WBS_type=development AND
            programs=yes OR
            other_software=yes
THEN        level_2=Software_Support
            X=(X+1)
DISPLAY     "1.{X}          {level_2}"
RESET       level_2;


RULE 650

IF          occ=yes AND
            WBS_type=production AND
            material=yes
THEN        level_2=Interim_Contractor_Support
            X=(X+1)
DISPLAY     "1.{X}          {level_2}"
RESET       level_2;

ASK material:"
Will the contractor(s) furnish material and maintenance
pending assumption of these services by the military?
";


RULE 660

IF          occ=yes AND
```

```
            WBS_type=production AND
            destination=yes
THEN        level_2=First_Destination_Transportation
            X=(X+1)
DISPLAY     "1.{X}          {level_2}"
RESET       level_2;

ASK destination:"
Will {program} be delivered from a procurement source
outside the Department of Defense inventory to the first
point of use or storage for subsequent distribution within
the Air Force?
";


RULE 670

IF          occ=yes AND
            WBS_type=production
THEN        level_2=Warranty
            X=(X+1)
DISPLAY     "1.{X}          {level_2}"
RESET       level_2;


RULE 680

IF          occ=yes AND
            WBS_type=production
THEN        level_2=Hardware_Quality_Audit
            X=(X+1)
DISPLAY     "1.{X}          {level_2}"
RESET       level_2;


RULE 690

IF          ogc=yes AND
            WBS_type=development
THEN        level_2=Flight_Test
            X=(X+1)
DISPLAY     "1.{X}          {level_2}"
RESET       level_2;


RULE 700

IF          ogc=yes AND
            WBS_type=development OR
            WBS_type=production
THEN        level_2=Award_Fee
            X=(X+1)
DISPLAY     "1.{X}          {level_2}"
```

```
RESET      level_2;


RULE 710

IF         ogc=yes AND
           WBS_type=development OR
           WBS_type=production
THEN       level_2=Industrial_Mod_and_Improve_Prog
           X=(X+1)
DISPLAY    "1.{X}          {level_2}"
RESET      level_2;


RULE 720

IF         ogc=yes AND
           WBS_type=development OR
           WBS_type=production
THEN       level_2=Mission_Support
           X=(X+1)
DISPLAY    "1.{X}          {level_2}"
RESET      level_2;


RULE 730

IF         ogc=yes AND
           WBS_type=development OR
           WBS_type=production
THEN       level_2=Engineering_Change_Orders
           X=(X+1)
DISPLAY    "1.{X}          {level_2}"
RESET      level_2;


RULE 740

IF         ogc=yes AND
           PMD4=yes
THEN       level_2=Government_Furnished_Equipment
           X=(X+1)
DISPLAY    "1.{X}          {level_2}"
RESET      level_2;

ASK PMD4:"
Does the PMD or the System Program Office indicate that
Government Furnished Equipment is required?
";
```

```
RULE 750

IF          ogc=yes AND
            PMD5=yes
THEN        level_2=Aircrew_Training_Devices
            X=(X+1)
DISPLAY     "1.{X}          {level_2}"
RESET       level_2;


ASK PMD5:"
Does the PMD or the System Program Office indicate that
aircrew training devices (simulators) are required?
";


RULE 760

IF          ogc=yes AND
            PMD6=yes
THEN        level_2=Maintenance_Training_Devices
            X=(X+1)
DISPLAY     "1.{X}          {level_2}"
RESET       level_2;

ASK PMD6:"
Does the PMD or the System Program Office indicate that
maintenance training devices are required?
";


RULE 770

IF          WBS_type=development AND
            ogc=yes AND
            PMD7=yes
THEN        level_2=Other_tests
            X=(X+1)
DISPLAY     "1.{X}          {level_2}"
RESET       level_2;

ASK PMD7:"
Does the PMD or the System Program Office indicate that
other tests, that would not qualify as flight tests, are
required?
";


RULE 780

IF          ogc=yes AND
            value=yes
THEN        level_2=Mil_Standard_Requisition_Program
```

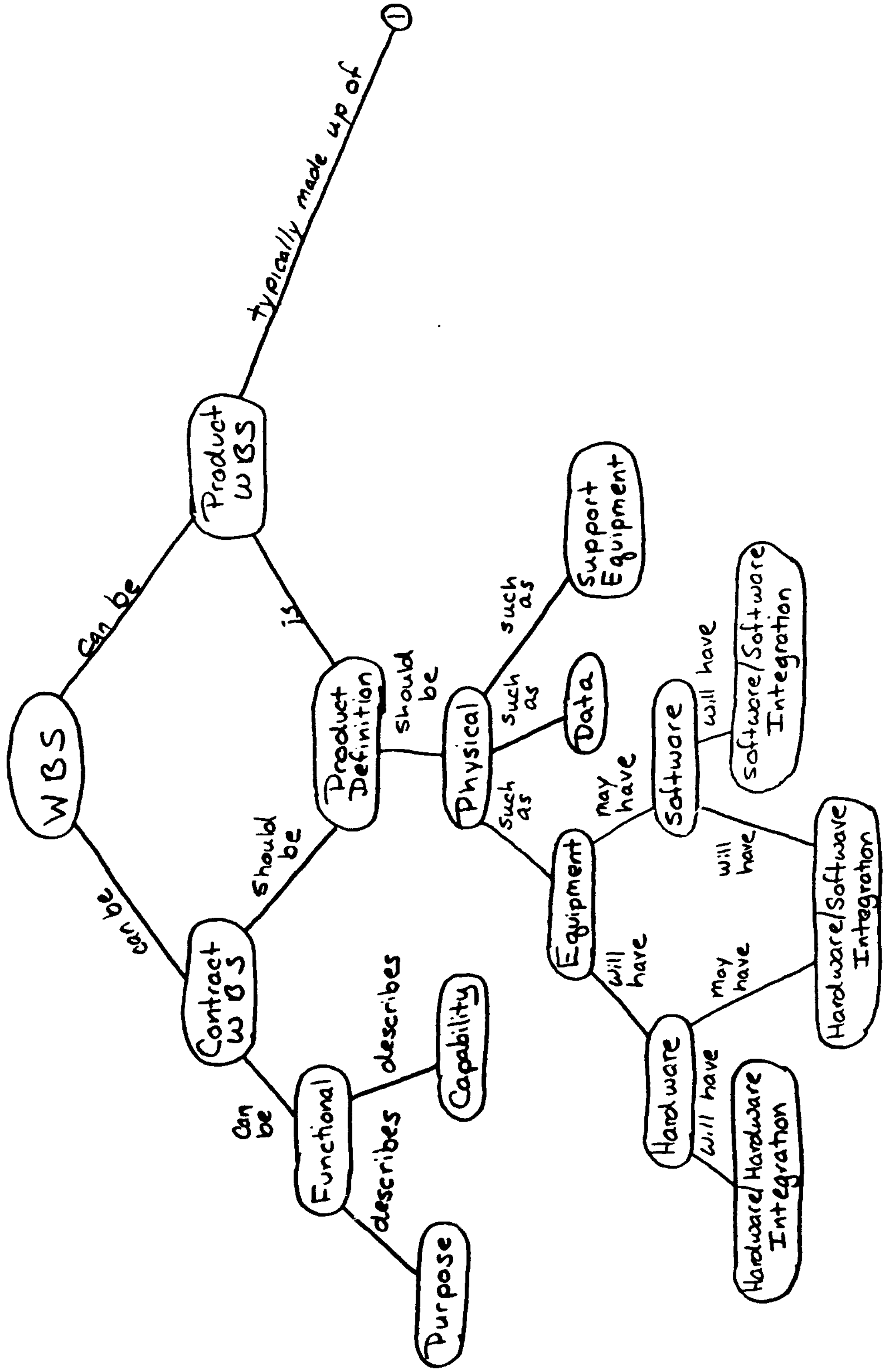
```
              X=(X+1)
DISPLAY       "1.{X}              {level_2}"
RESET         level_2;

ASK value:"
Does the contractor require low value government supply
items?
";
```

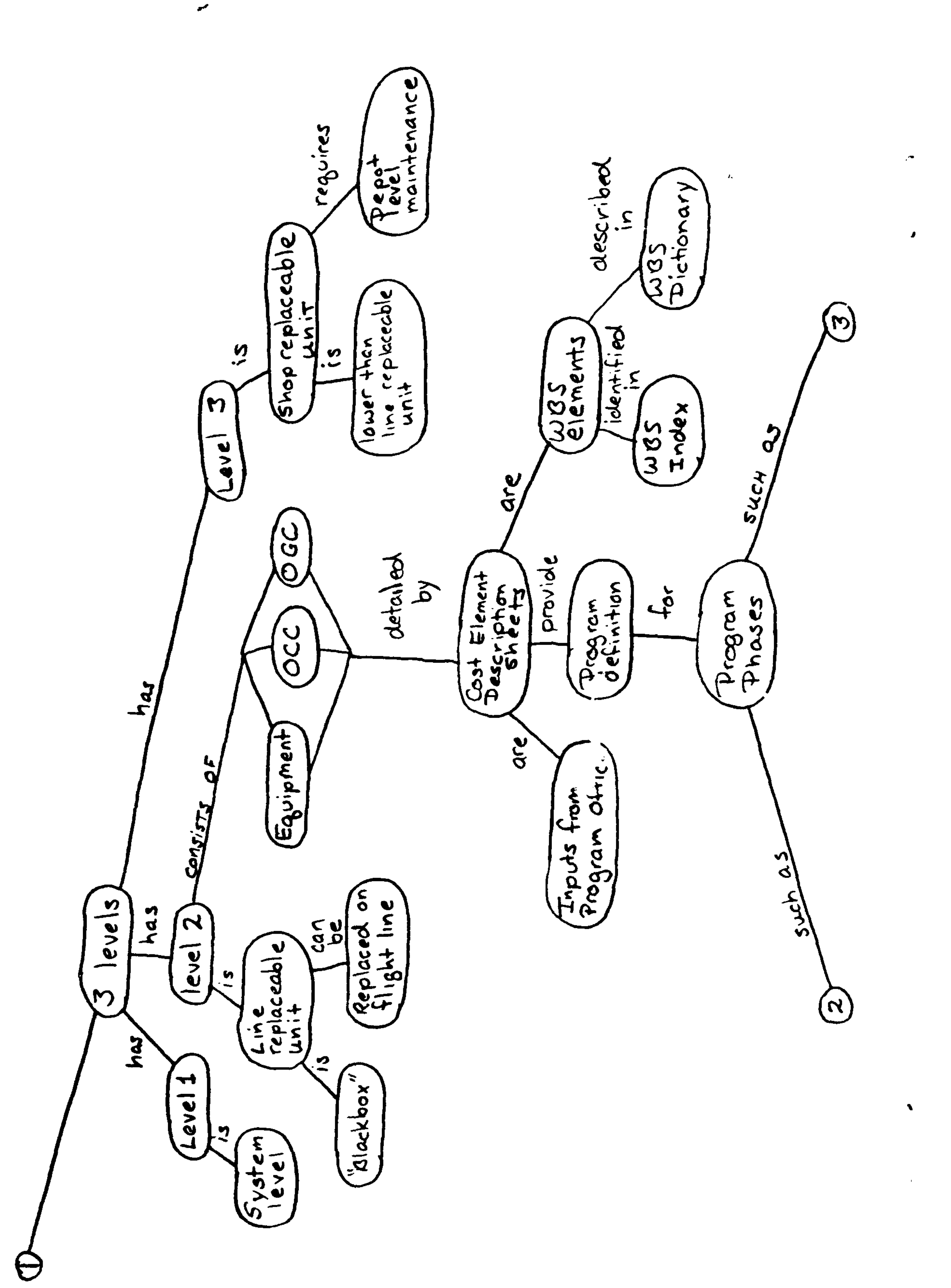
RULE 790

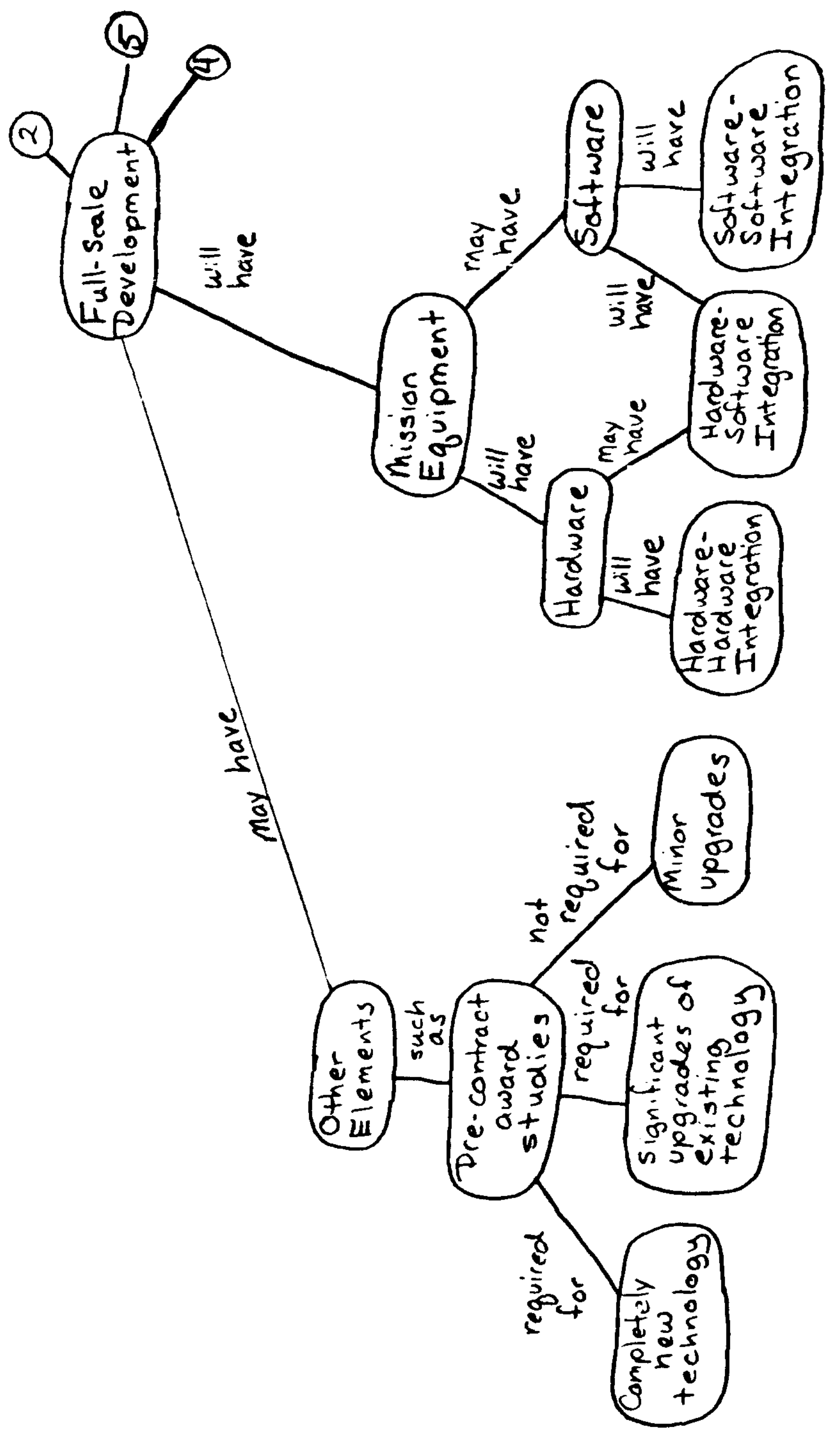
```
IF            WBS_type=production
THEN          level_2=Initial_Spares
              X=(X+1)
DISPLAY       "1.{X}              {level_2}"
RESET         level_2;
```

Appendix C: Concept Map of Expert's Knowledge of the Work Breakdown Structure

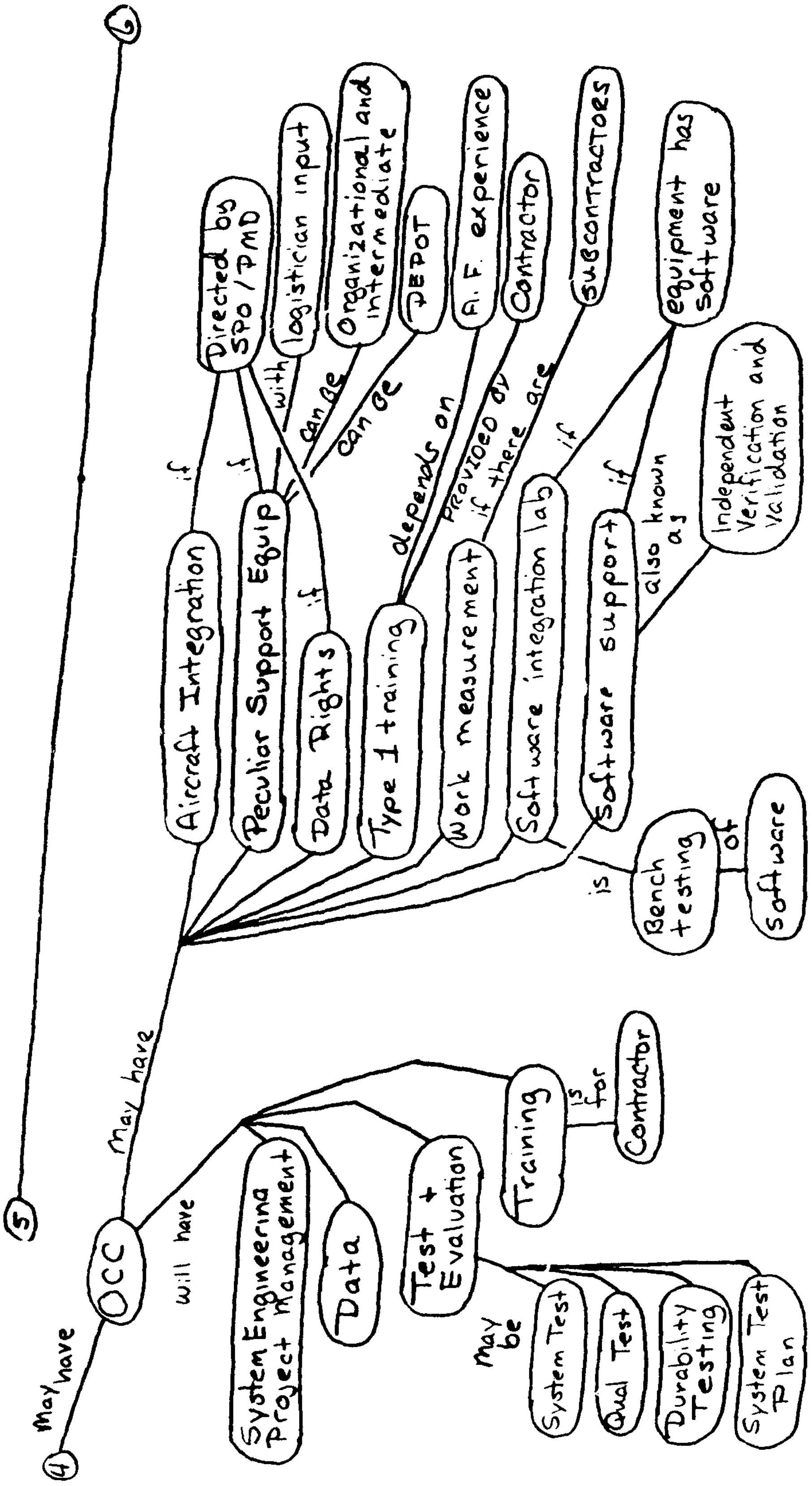
The following pages are the concept map that resulted from the three knowledge acquisition session with one expert. Due to the size and complexity of the map it cannot be reproduced on one page. To reconstruct the map, one must make copies of each page. Numbers on the end of each line segment correspond to numbers on line segments on the following pages. By matching these numbers, the concept map can be reconstructed in its entirety.


WBS
can be
Product WBS
typically made up of
1
can be
Contract WBS
should be
is
Product Definition
should be
Physical
such as
Support Equipment
such as
Data
such as
Equipment
may have
Software
will have
Software/Software Integration
will have
Hardware/Software Integration
will have
Hardware
may have
will have
Hardware/Hardware Integration
can be
Functional
describes
Capability
describes
Purpose

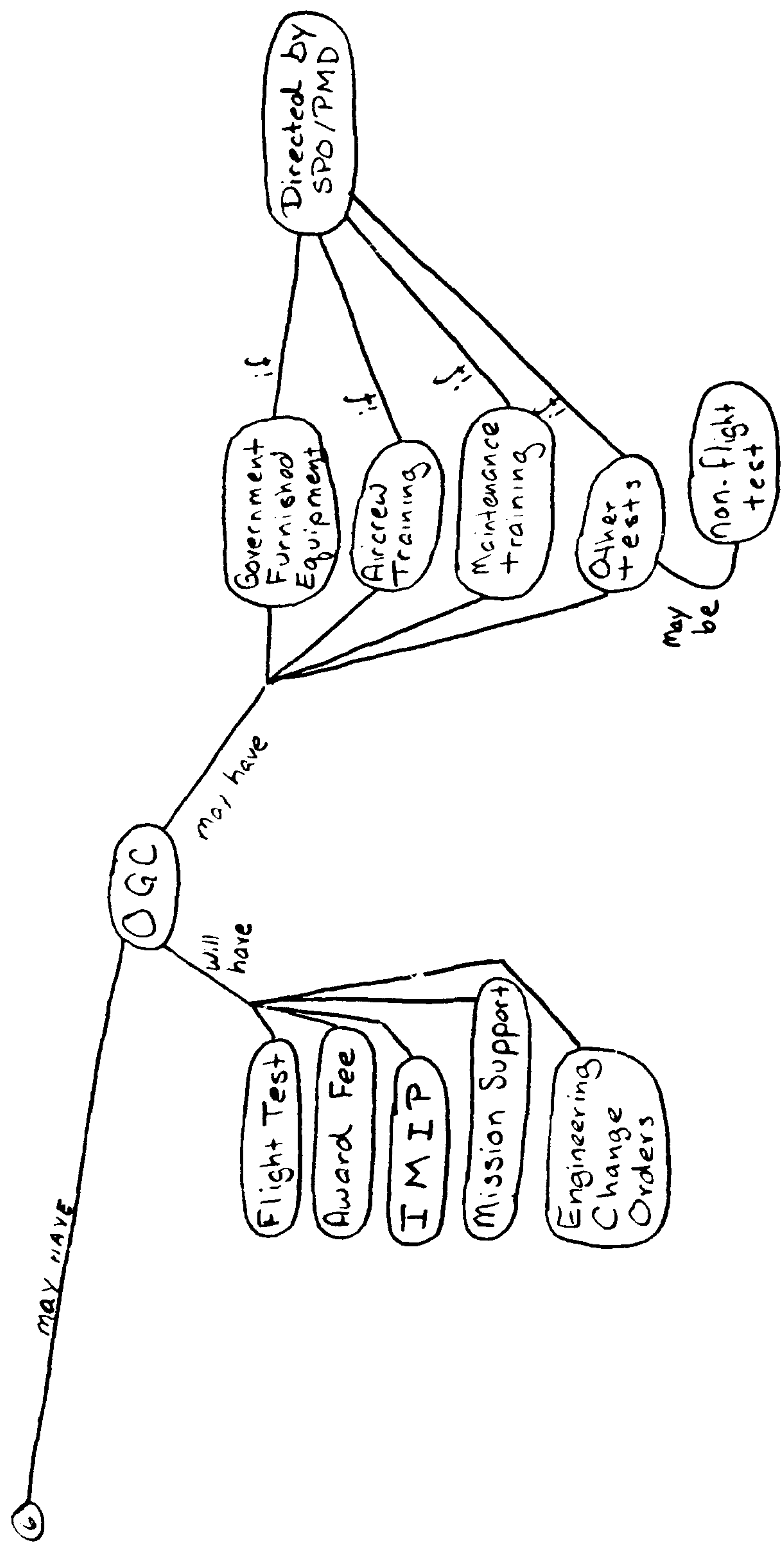

1
3 levels
has
Level 1
is
System level
has
level 2
is
Line replaceable unit
can be
Replaced on flight line
is
"Blackbox"
has
Level 3
is
Shop replaceable unit
is
lower than line replaceable unit
requires
Depot level maintenance
consists of
Equipment
OCC
OGC
detailed by
Cost Element Description Sheets
are
Inputs from Program Offic.
provide
Program definition
for
Program Phases
such as
2
such as
3
are
WBS elements
identified in
WBS Index
described in
WBS Dictionary

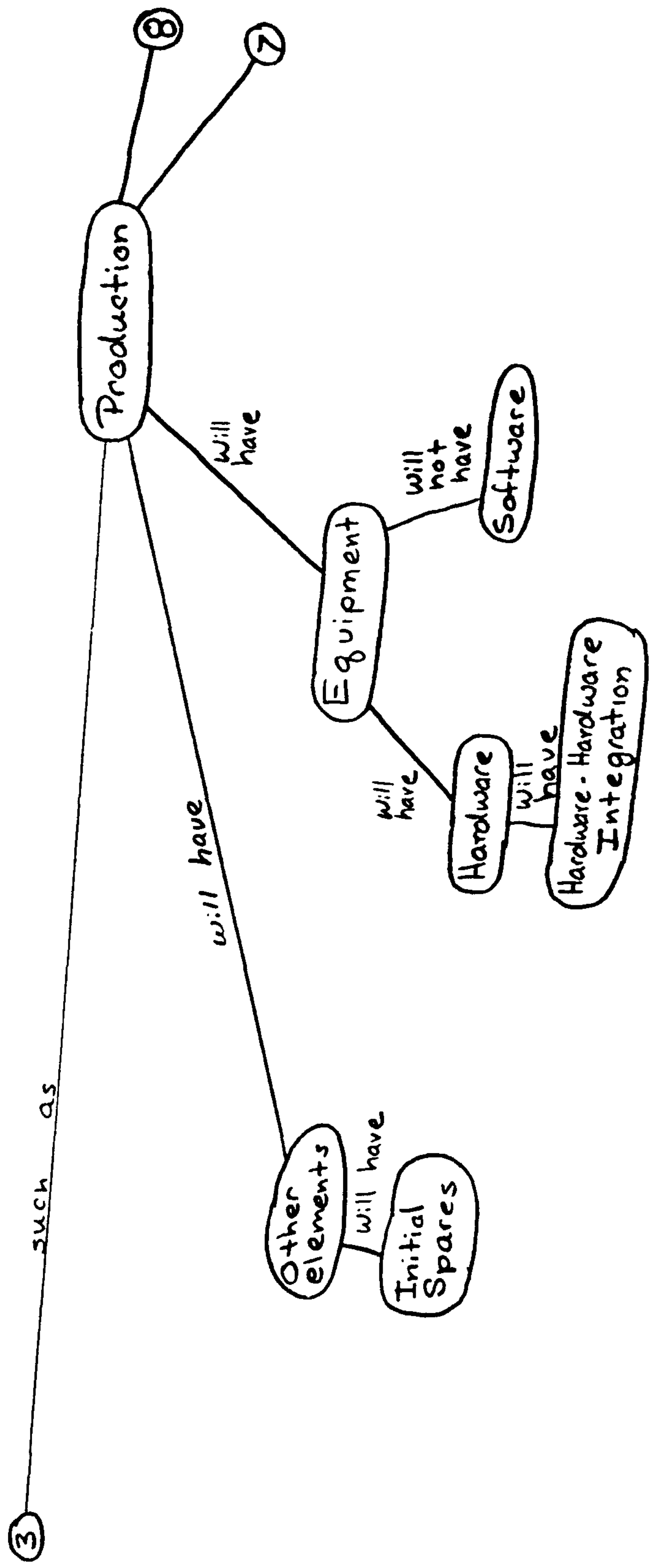


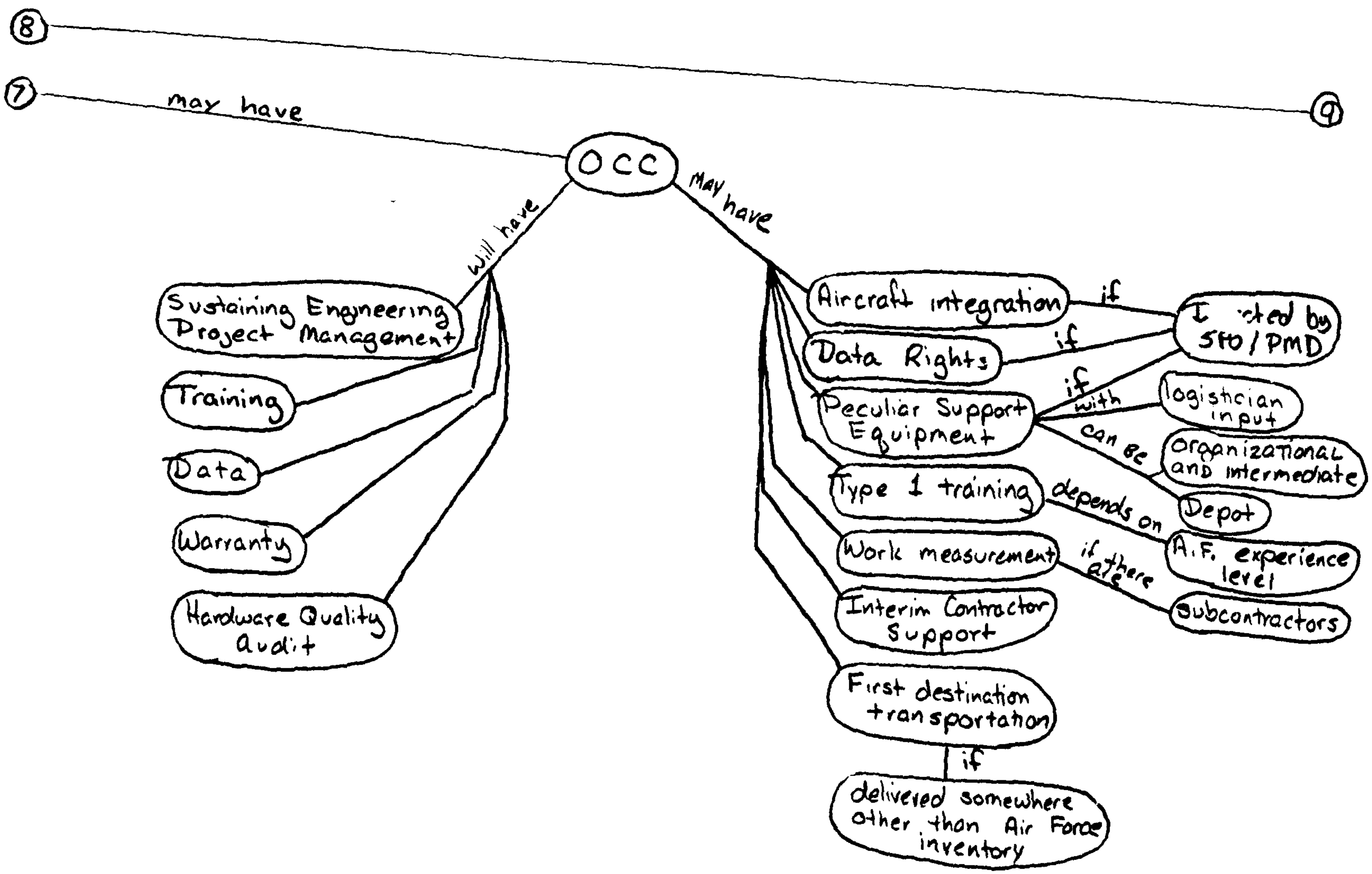
Full-Scale Development
2
5
4
will have
Mission Equipment
may have
Software
will have
Software-Software Integration
will have
Hardware-Software Integration
will have
may have
Hardware
will have
Hardware-Hardware Integration
may have
Other Elements
such as
Pre-contract award studies
not required for
Minor upgrades
required for
Significant upgrades of existing technology
required for
Completely new technology



4
May have
OCC
5
6
May have
will have
System Engineering Project Management
Data
Test + Evaluation
may be
System Test
Qual Test
Durability Testing
System Test Plan
Training
is for
Contractor
Aircraft Integration
Peculiar Support Equip
Data Rights
Type 1 training
Work measurement
Software integration lab
Software support
is
Bench testing
of
Software
if
Directed by SPO/PMD
with
logistician input
can be
Organizational and intermediate
can be
DEPOT
depends on
A. F. experience
PROVIDED BY
Contractor
if there are
SUBCONTRACTORS
if
equipment has software
also known as
Independent Verification and Validation


MAY HAVE
OGC
Will have
may have
Flight Test
Award Fee
IMIP
Mission Support
Engineering Change Orders
Government Furnished Equipment
Aircrew Training
Maintenance training
Other tests
may be
Non-flight test
if
if
if
if
Directed by SPO/PMD


Production
8
7
will have
Equipment
will not have
Software
will have
Hardware
will have
Hardware - Hardware Integration
will have
Other elements
will have
Initial Spares
such as
3



8
7
may have
9
OCC
Will have
May have
Sustaining Engineering Project Management
Training
Data
Warranty
Hardware Quality audit
Aircraft integration
Data Rights
Peculiar Support Equipment
Type 1 training
Work measurement
Interim Contractor Support
First destination transportation
if
if
if
with
can be
depends on
if there are
I ...cted by SPO/PMD
logistician input
Organizational and intermediate
Depot
A.F. experience level
Subcontractors
delivered somewhere other than Air Force inventory

Bibliography

1. Abrett, Glenn. "The KREME knowledge editing environment," International Journal of Man-Machine Studies, 27:103-126 (August 1987).

2. Belkin, N.J. and H.M. Brooks. "Knowledge elicitation using discourse analysis," International Journal of Man-Machine Studies, 27:127-144 (August 1987).

3. Berry, Dianne C. "The problem of implicit knowledge," Expert Systems The International Journal of Knowledge Engineering, 4:144-151 (August 1987).

4. Bregard, Carolyn and Harold J. Schutt. "The Program Manager's Support System (PMSS): An Executive Overview and Description of Functional Modules." Defense Systems Management College, Fort Belvoir Virginia, 1989.

5. Cleaves, D. A. "Cognitive biases and corrective techniques: proposals for improving elicitation procedures for knowledge-based systems," International Journal of Man-Machine Studies, 27:155-166 (August 1987).

6. Department of the Air Force. Work Breakdown Structure (WBS) for Defense Materiel Items. AFR 800-17. Washington: HQ USAF, 2 May 1975.

7. Department of Defense. Work Breakdown Structures for Defense Materiel Items. MIL-STD-881A. Washington: Government Printing Office, 25 April 1975.

8. Gordon, Raymond L. Interviewing: Strategy, Techniques, and Tactics. Homewood, Illinois: The Dorsey Press, 1975.

9. Heatherton, James and Todd T. Vikan. An Introduction to Expert Systems and Knowledge Acquisition Techniques. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September 1990.

10. Kahn, Gary S. et al. "A mixed-initiative workbench for knowledge acquisition," International Journal of Man-Machine Studies, 27:167-179 (August 1987).

11. Kerzner, Harold. Project Management: A Systems Approach to Planning, Scheduling, and Controlling. New York: Van Nostrand Reinhold, 1989.

12. Madni, Azad M. "The Role of Human Factors in Expert System Design and Acceptance," Human Factors, 30:395-414 (August 1988).

13. Moose, Anne and Dan Schafer. VP Expert: Rule-Based Expert System Development Tool. Paperback Software International, 1987.

14. Novak, Joseph D. and D. Bob Gowin. Learning How To Learn. Cambridge: Cambridge University Press, 1984.

15. Olson, Judith R. and Henry H. Rueter. "Extracting expertise from experts: Methods for knowledge acquisition," Expert Systems The International Journal of Knowledge Engineering, 4:152-167 (August 1987).

16. Schoen, Seymour and Wendell G. Sykes. Putting Artificial Intelligence to Work: Evaluating and Implementing Business Applications. New York: John Wiley and Sons, Inc. 1987.

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13. ABSTRACT *(Maximum 200 words)*
The acquisition of expert knowledge is recognized as one of the major hurdles facing the expert system programmer or knowledge engineer. Unfortunately, knowledge acquisition is seldom addressed in any detail in expert system literature, even though there exist a number of different techniques that a knowledge engineer can use to capture expert knowledge. The purpose of this study was to identify and evaluate the relative effectiveness of three knowledge acquisition techniques that may be used when developing expert systems for project management related tasks. The three techniques were interview, concept mapping, and interruption analysis. An experiment was conducted and quantitative measures of effectiveness were derived. These measures included technique implementation times, times to formulate expert system production rules, the total number of rules and the inferences required to complete those rules, the number of translations of the expert knowledge to encode an expert system rule, and the contribution each technique made to a final expert system that represented an aggregate of all the expert knowledge collected. While no one technique was clearly superior, used together, concept mapping and interruption analysis were found to be powerful tools.

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